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THE

NORTH-ATLANTIC SEA-BED:

COMPRISING

A DIARY OF THE VOYAGE ON BOARD H.M.S. BULLDOG, IN 1860;

AND

OBSERVATIONS ON THE PRESENCE OF ANIMAL LIFE, AND THE FORMATION AND NATURE OF ORGANIC DEPOSITS, AT GREAT DEPTHS IN THE OCEAN.

88387

BY

G. C. WALLICH, M.D., F.L.S., F.G.S.,

SURGEON ON THE RETIRED LIST H.M. INDIAN ARMY; NATURALIST TO THE EXPEDITION DESPATCHED IN THE ABOVE YEAR, UNDER COMMAND OF SIR F. L. M'CLINTOCK, R.N., TO SURVEY THE PROPOSED NORTH-ATLANTIC TELEGRAPH ROUTE BETWEEN GREAT BRITAIN AND AMERICA.

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TO

HIS GRACE THE DUKE OF SOMERSET, K.G.,

FIRST LORD COMMISSIONER FOR EXECUTING THE OFFICE OF LORD HIGH ADMIRAL OF GREAT BRITAIN AND IRELAND,

THIS VOLUME,

EMBODYING A SMALL CONTRIBUTION TO THE NATURAL HISTORY OF THE SEA,

IS,

BY PERMISSION,

MOST RESPECTFULLY AND GRATEFULLY

DEDICATED

BY

THE AUTHOR.

THE

NORTH-ATLANTIC SEA-BED.

PART I.

CHAPTER I.

DEPARTURE FROM STORNOWAY.—THE FARÖE ISLANDS.—SUSPIRIA DE PROFUNDIS.—BASALTIC DRIFT.—EFFECTS OF DEEP-SEATED CURRENTS.—VOLCANIC DETRITUS ALONG SEA-BED.—DEEP ARCTIC CURRENT.—THE WESTMANN ISLANDS.—ASPECT OF SOUTHERN ICELAND.—CHARACTER OF THE SEA-BED ALONG ITS SHORE.—ARRIVAL AT REKIAVIK.—ICELANDIC SCENERY.—GREAT LAVA-STREAMS.—ABRASIVE NATURE OF THE SCORIACEOUS ROCK.—OBSIDIAN DUST.—MODIFICATION OF SIR JOHN ROSS'S SOUNDING "CLAMS."—EFFECTS OF RECENT ERUPTION OF KOTLA.—EJECTION OF ICE FROM CRATER.—EXPLANATION OF THIS PHENOMENON.—PREVALENCE OF SICKNESS DURING VOLCANIC ERUPTIONS.

ON the 2nd of July, 1860, H.M.S. Bulldog steamed out of the little harbour of Stornoway, and our North-Atlantic cruise fairly commenced.

July 4.—For the first time since leaving Spithead, now eleven days ago, the sun has shone out brightly, and we are revelling in a glorious summer morning. About an hour after midnight the "Dimon Rocks" were sighted, although distant between thirty and thirty-five miles; so that we are already in the region of no night.

Nothing could exceed the beauty of the panorama presented to our view, as, one after another, the bold headlands of the Faröe Islands burst upon us. Although no vestige of tree or shrub clothes the declivities, and the sombre tints of the trap rock are relieved only here and there by brilliant patches of green-sward, or orange-tinted lichens, so varied is the outline, and intersected with

chasms and sparkling water-courses, that all idea of monotony is lost in the general grandeur of the scenery.

Suddenly the magnificent fiord which separates Stromöe and Naalsäe, the two principal islands of the group, from each other, opened out upon us. Sweeping round a bold headland into this, we at once found ourselves surrounded by lofty hills, whose bases, broken up into every variety of cliff and cavern, formed the water-line, whilst their summits might be seen, far in the background, stretching beyond an alternating series of ridges and chasms, until they attained the height of from 1500 to 2000 feet.

In some of the more elevated hollows large drifts of dazzling snow still lingered, and gave token of a late and boisterous winter. Strange to say, these drifts were principally observable on the southern slopes.

But the most charming feature was the constant succession of torrents and cascades which dashed impetuously downwards to the fiords, and looked in the distance like so many living streams of alabaster; whilst around the summits of the ranges whence they sprung the layers of grey mist hung for a moment or two, as if clasping them in a parting embrace, and then glided away, or became dissipated in the atmosphere around.

Continuing our course along the fiords, which were rarely less than from one to two miles across, we speedily reached Thorshaven, the chief town of the Faröe Islands, took on board a pilot, and finally came to anchor, about noon, at the entrance to the little land-locked bay of Westmannshaven.

Having hired a boat, and satisfied my curiosity by a ramble ashore, I devoted the remainder of the afternoon to dredging.

July 6.—Too foggy yesterday to leave the anchorage and get to sea again. Towards evening the rain, which came down in torrents during the afternoon, cleared off. I sat up till midnight, and at that hour took a sketch of the village and harbour. The pink tints left by the setting sun were still visible on some clouds that floated away behind the western range of hills, and it seemed almost impossible to believe that night was so far advanced.

Up anchor and away at 7 A.M. The morning gave promise of fine weather; but it soon became foggy again, and we were accordingly doomed to lose all save a partial glimpse of the famed promontory of "Mühlen Head." But even this glimpse afforded an idea of its grandeur; for, steering along almost within

stone's-throw of the shore, we could discern its perpendicular character, and the mighty blocks of detached cliff standing out from the main mass like outworks to some Titanic fortress. In ten minutes after catching our parting view of this towering headland, we were running along merrily with a clear blue sky overhead and sunshine; so that the demon of the Faröese mist only remained faithful to his own traditions.

Several soundings have been taken today; but these are of no interest, being from shoal water. Although it is blowing fresh from N.W. almost directly in our teeth, the last cast was "up and down"—showing how admirably a fixed position may be maintained under steam, even in bad weather. Another sounding is going on whilst I write. It is midnight, and yet the light streams down through my cabin windows.

July 9.—The weather, which has been bad enough for the past two days, threatens to become still worse. This is provoking; for under more favourable circumstances we should, ere this time, have sighted the coast of Iceland, somewhere in the vicinity of Ingolfshofde, and been near enough to the land to see Hecla and the new volcano which burst into activity in May last. As it is, the ship has been kept well clear of the land, and we shall, in all probability, lose a very grand spectacle.

From five to six soundings have been taken daily, the intervals varying from a few miles, in the neighbourhood of the coast-lines, to a degree, or thereabouts, at mid-distance between them. In the examination of the material brought up, my time has been so fully occupied, that anything like a few hours' continuous rest is out of the question.

Already my views, regarding the extension of animal life to much greater depths than is usually allowed, have received a certain degree of confirmation. In a sounding (No. 15) taken yesterday, at a point about two-thirds of the distance between the Faröes and Iceland, the Conical Cup* brought up, from a depth of 682 fathoms, a piece of quartz-rock about an inch square, several fragments of basalt, an old and much-worn fragmentary valve of *Pollicipes*, a minute pellet of mud about the size of a pea, a calcareous *Serpula*-tube—about

* For a description of this and other forms of Sounding apparatus alluded to in the Diary, the reader is referred to the Chapter on Sounding and Sounding Apparatus. The organisms referred to will be found described in the Chapters devoted to Natural History.

half an inch in length, and evidently just broken off from the stone to which it must have been attached, inasmuch as the fleshy matter was perfectly fresh at the point of fracture—and lastly, a minute *Spirorbis* and two shells of *Truncatulina lobata* still adherent to small stones and apparently alive. Leaving the discussion of the conditions essential to the maintenance of animal life at great depths to be set forth in another chapter, two very remarkable facts remain to be noticed in connexion with this sounding. The first of these is the almost entire absence of any soft deposit at a spot which, according to the evidence afforded by the progressive depths noted on either side, would appear to be the deepest portion of the sea between the Faröe Islands and the south-west part of Iceland. The second is the rolled condition of the basaltic gravel.

Now, although it is quite clear that the small trace of mud brought up in this sounding is, of itself, no proof that soft deposit does not occur in considerable quantity, the absence of such deposit is rendered probable by the presence of permanently sessile Annelids and Foraminifera; inasmuch as these creatures could not exist at all, save at the immediate surface of the sea-bed, or in water free from currents of sufficient velocity to dislodge or remove them.

On the other hand, the rounded basaltic gravel would, at first sight, appear to countenance the existence of a rolling action such as a current would produce. And doubtless these pieces of gravel have, at one time or other, been reduced to their present form by such a force. But certain appearances on their surface would indicate their long-continued retention at the point from which they were brought up. Thus, although for a depth of about $\frac{1}{30}$th of an inch the basalt is of the most compact kind, the stone has completely changed colour from its normal glistening black to an ochreous yellow, owing to long immersion. This ochreous layer is in other respects identical with the mass within, and cannot possibly be mistaken for an incrustation formed from without. In a sounding obtained early this morning, rounded masses of basalt were again met with, but the depth in this case was only 64 fathoms. If the former were dropped from drifting icebergs, in their rolled condition, it must have been under a widely different order of things from that in operation now; for no iceberg has ever been known to traverse this region. It is probable, therefore, that the bed of the ocean has subsided, and that these rolled masses have rested in their present position from a period when currents or tides of sufficient power to produce their

rounded shape swept across it. But although no current now exists in this locality capable of producing such an effect, or of transporting masses of mineral matter even as small as those under notice, there appears to me to be strong evidence in favour of an offshoot of the Arctic current slowly moving downwards between the Faröe Islands and Iceland.

It has been calculated that an ordinary stream, running at the rate of no more than 300 yards an hour, is capable of disintegrating and carrying away fine clay; that a rate of 800 yards (or somewhat less than half a mile) an hour, will suffice to transport coarse sand; whilst a current running a mile and a half, will roll along rounded pebbles as large as a hen's egg,—the inertia of stones of ordinary specific gravity (that is, from 2·5 to 2·8) being reduced by more than a third on their immersion in water. At extreme depths, and in water surcharged under an enormous pressure with saline matter, the inertia of masses of stone would be still further reduced; and although a diminution of friction between them would accompany this reduction, the general result would be materially influenced, inasmuch as masses which could not otherwise have been dislodged would now cooperate in the rolling action. This is a very material point, and one which I cannot help thinking has been lost sight of, in a great measure, by those who argue that, however strong a current may be, the lower stratum of water is so retarded by friction against the bottom as almost entirely to lose its initial velocity.

Supposing the bed of the sea to be perfectly level, the retardation would no doubt take place. But where very slight inclinations of the surface occur, so as to allow fresh portions of the water to impinge on the sand or gravel, it will at once be apparent that the primary force would at all events retain the greater portion of its influence.

In the case of plateaus of moderate area, the surfaces of which happen to be raised above the general level of the sea-bed, and more especially if they have a fall tending in the same direction as a deep-seated current, the entire force of the latter would take effect in rolling and transporting stones, as well as in wearing down the surface.

I have stated that the sounding (No. 15 in the list) gives the greatest depth, in the line from the Faröes to Iceland, about two-thirds of the way across, or, in round numbers, about ninety miles to the eastward of Ingolfshofde. It is a very

remarkable fact that, throughout the entire distance, nearly 200 miles, between the point at which this sounding was taken and the Faröes, not the slightest trace of volcanic detritus appears in the material brought up from the bottom. Between long. 7° 55′ and 13° 45′ inclusive, eleven casts were made, and bottom brought up five times; so that, had volcanic particles been present, some trace of them must at all events have been observable. This becomes the more remarkable when it is borne in mind that, during eruptions of Hecla and Skaptar Jokul, the volcanic particles have been borne across the whole breadth of the North Sea, to the coast of Norway, in nearly the same parallel of latitude as the Faröes. It is difficult, therefore, to conceive that this large area of sea-bed, or at any rate that portion of it constituting the middle third of the distance alluded to, should not have received a share of the deposit, under favourable conditions as to atmospheric currents.

On the other hand, from the 682-fathom locality to our present position, which I should say is not more than forty miles from the southern shore of Iceland, out of eight casts, seven on being brought up have each presented volcanic detritus.

Combining all these facts together, I am clearly of opinion that a deep-seated drift, bringing the colder waters from Spitzbergen and the western side of Nova Zembla, sets along this middle tract and bears away with it the volcanic debris. We know that the Arctic drift splits up into two branches, as it were, on coming across the northern shores of Spitzbergen: one branch, passing down to the south-westward and carrying along with it the mass of ice which hugs the eastern coast of Greenland, doubles Cape Farewell, and then streams up along the western shores of Greenland,—the other branch being traceable for several degrees to the southward and eastward of Spitzbergen, and then gradually lost in the fork of the Gulf Stream, the western arm of which ascends in a due northerly direction, so as to impinge against the southern portion of Spitzbergen, whilst the other arm, turning aside at nearly a right angle, assumes an easterly course. That branch of the descending or Arctic drift which is traceable into the bifurcation of the ascending or Gulf Stream must find its way somehow to the Equator; and, as a natural consequence, it follows the recognized practice of all cold currents when brought into contact with warmer ones, and thus travels below it to its destination. Continued in its original course, this current would traverse

the middle space between the Faröes and Iceland; and, as has been shown, if moving at no greater velocity than 600 yards (that is, about one-third of a mile) per hour, or half the speed at which we know the western superficial branch moves round Cape Farewell, it would be quite powerful enough, independently of the decrease in the specific gravity of particles of mineral matter owing to the conditions already discussed, to bear along those particles and thus to remove all trace of debris other than that reproduced by its own action. By means of this current, the volcanic particles which, according to Captain Maury, strew the bed of the Mid-Atlantic, between the parallels of 47° and 52°, along no less than twenty-five degrees of longitude, are borne down from the Icelandic coasts. In the "Notes"* published by me immediately after my return from the cruise, I adverted to this as being the true source of the volcanic matters present in the latitudes referred to, and thus corroborated the shrewd suggestion of the late Professor Bailey.

I think we are therefore warranted in assuming that a current having a moderate velocity, such as that referred to as being sufficient to account for the phenomena in question, does exist, and that it flows away in a south-westerly course, under the warmer waters of the ascending Gulf Stream, and gradually mingles with the general gathering of the polar waters around the Equator,—an additional proof of the correctness of this view being derived from the fact, fully borne out by various navigators, that about the 63rd parallel of latitude the temperatures of the surface-water and that at a hundred fathoms' depth do not usually differ by more than three degrees—clearly indicating that, at one-sixth of the greatest recorded depth of water, the temperature of the Gulf Stream has not yet been materially diminished, and, inversely, that the cold drift is still too deep-seated to have been in operation at that distance from the surface.

July 10.—Strong head winds, cold drizzling fogs, or drenching rain, with a nasty chopping sea, have haunted us ever since we drew near to "The Inferno." Our course has been close to the northward of the Westmann Islands, a group of purely volcanic origin, and abounding in magnificently bold scenery. Most of the islands consist of trappean rock thrust up sheer from the sea to a height of several hundred feet. In one place the entire face of one of these huge masses has been rifted off and hurled forwards as it were, its angle of inclination being

* "Notes on the Presence of Animal Life at vast Depths in the Sea."

so great as to give it the appearance of being about to crash headlong into the waters beneath. In a second mass of nearly similar dimensions one half has become partially submerged, whilst the other defiantly stretches forth its rugged and perpendicular front to the waves that lash themselves into a frenzy in their effort to make it yield also. On the land side, the mountain-chains, whenever it was possible to snatch a momentary glimpse of them by the uplifting of the clouds, presented a most weird appearance, and told of the terrific forces which were in operation at their upheaval. But Hecla, Eyefialla, Kotlugia, and Skaptar Jokul remained provokingly hidden from view; and after straining my eyes for several hours, and vainly endeavouring to deceive myself into the belief that every towering cone whose summit was swathed in mist must be belching forth its sulphurous torrent, I was at last glad to beat a retreat, and go to my "Plutonic tallies" (as Captain Maury calls them) obtained from the regions below.

Whilst the increase in depth of water, from the north-west angle of the Faröes, was singularly gradual and regular till we reached the vicinity of the 682-fathom point, from thence to the south-westerly part of Iceland the evidence of a more recent igneous-rock formation at once discloses itself in a series of alternating elevations and depressions. Thus, at a distance of about forty miles to the westward we find 64 fathoms; then a plateau of nearly seventy miles diameter, on which the depth varies between 40 and 100 fathoms; and lastly, another dip of 640 fathoms, which decreases to 445 fathoms at fifteen miles distance from the Icelandic coast.

Now these alternations of level are by no means great; and, so far as the soundings show, there is no reason whatever why a telegraphic cable should not sink down into the position destined for it, even if run transversely across all these ridges and hollows. But this is only on the supposition that the depths indicated are really the greatest that exist, and that, along the intervals, other depressions and elevations, more or less sudden as the case may be, do not occur. If one can judge from the character of the islands we have passed today, namely the Westmanns, and from that of the mainland, so far as the mists have allowed us to catch a glimpse of it, it would seem highly probable that the alternations are infinitely more frequent, and consequently that a survey of a sufficiently comprehensive kind to indicate the direction and extent of the valley-lines is absolutely indispensable, if a cable is to be submerged in this direction

with the slightest prospect of safety. Wherever the submarine valleys happen to be narrow and irregular, no matter how slowly a cable may be paid out, festoons would form, the weight of which, acting on the points of contact, would inevitably engender a fatal strain. Whether the strata at the bottom be of the more recent or ancient igneous character, the danger of abrasive action would exist in an equal degree so long as the ridges supported the layer of emery-like deposit which prevails along the southern coast-line of the island; and, as already stated, the only mode of counteracting this danger is to deposit a cable, not across the endless series of sharp ridges, but along the most suitable of the valleys protected by them.

July 12.—Rekiavik. After rounding Rekianess the evening before last, in a stiff gale from the southward, and having seen quite as much as was desirable of the reef-bound coast that stretches for some distance to the east of that Cape, we dropped anchor yesterday morning at Rekiavik. Whether owing to the still gloomy state of the weather, or a certain demure look inherent in the place, the first feeling engendered, on taking a survey of it from our anchorage, was one of unmingled disappointment. Instead of a picturesque town nestling, like a sea-bird, at the base of vast broken cliffs such as one might expect to come across in an intensely volcanic region, a range of straggling wooden houses extending along a low, somewhat broken slope, on which no trace of verdure was observable, with a murky background of mist solid enough to have concealed Paradise, was all that met our gaze. The peculiar summer (of 1860) had evidently "set in with its accustomed severity" in these, as in our own lower latitudes; and it was not until a late hour in the evening that the sky cleared, and revealed the glorious amphitheatre by which Faxe fiord is surrounded. During a few moments of sunshine, the effect was almost magical,—the distant snow-capped ranges of mountain, which shut out the horizon to the north-westward, being brought forward with a distinctness not only of outline but of detail, that would have made them appear close to the eye, but for the multitude of intermediate peaks which glistened as if suddenly transformed into a tempest of adamant; whilst some sixty miles distant to the north-westward might be seen the gigantic cone of Snæfells, towering up from the sea in isolated grandeur.

There is something singularly impressive in the knowledge that we are standing on the threshold of the mightiest convulsions the surface of our planet

has witnessed. Although fully alive to the fact that, throughout the globe, a mere crust intervenes between us and the vestiges of similar phenomena, it is not until our feet press the blistered lava-bed, and we actually see around us the vast blocks which once fell thundering into the positions they still occupy, that the mind wakes to a conception of the sublimity and grandeur of such a scene.

The whole of the south-western peninsula of Iceland presents the appearance of having been poured forth as a vast continuous lava-stream. Along the eastern boundary of this tract may be seen a number of well-defined cones, which constitute the flank company of a series extending diagonally across to the north-eastern extremity of the island. Those in the neighbourhood of Rekiavik, and stretching in a south-westerly direction down towards Rekianess, would seem to have been thrust up at a period anterior to the passage of the great lava-stream, inasmuch as they rise up suddenly from the general level, and thus indicate its gradual elevation around their bases. But at the present day there remains no direct evidence to show from whence the stream flowed. The distance of its central portion from the two great southern foci of convulsion, namely Hecla and Eyefialla, is about sixty miles. It is nevertheless quite possible that it may have flowed from one of these, inasmuch as, during the eruption of Skaptar Jokul in 1783, two streams were given off, one of which extended to a distance of fifty miles, with a breadth varying from twelve to fifteen miles, and an average depth, where spread out on flat tracts, of 100 feet; whilst the other reached to a distance of forty miles, with an average breadth of seven miles, and the same depth as the previously mentioned stream. But in some of the gorges, between the mountains through which these streams forced their way, they actually attained the enormous depth of upwards of 600 feet.

The shore along the fiord near Rekiavik is composed entirely of huge scoriaceous blocks of lava, the colours of which vary from a slaty blue, to purple, brick-red, and black. All are more or less spongy in their structure, and, except where they have been subjected to attrition within the tide-marks, retain the sharp irregular emery-like surface so characteristic of the lavas and pumice masses. Even the small boulders and pieces of shingle along the water-line, which have been subject to long-continued violent attrition against each other, although rounded in outline, present the same peculiarity; whilst the resultant

sand consists of minute angular particles which never lose their primary keenness, under any amount of comminution. The same remark applies to the more glassy obsidian-like substance of which the soundings on the southern coast consist. This deposit has been derived, in all probability, from the atmosphere during the eruptions; and it is somewhat extraordinary that it should be almost entirely free from particles of true lava or pumice. So far as the soundings have hitherto gone, this peculiarity is invariably observable. It would therefore appear that the clouds of volcanic dust with which the atmosphere is loaded, and which has been known to extend to the coasts of Norway, the Faröe Islands, and even Shetland, constitute the true basis of the molten mass of the volcano, the lavas and pumice being the overflowing scum that collects upon its upper surface.

As far as I have been able to learn from persons who have travelled in the neighbourhood of the obsidian veins, these do not occur at great elevations on the sides of the volcanic cones, but appear suddenly and end as suddenly. Should this really prove to be the case, it would indicate that the streams of obsidian were poured out through lateral channels, situated below the level at which the fused mass within the body of the volcano assumes its frothy character. Pent up as is the gaseous matter within the cellular cavities, under an inconceivably vast pressure, it is easy to perceive that such portions as are thrown up from the mouths of the crater itself would be shivered into innumerable minute atoms on escaping into the atmosphere, and, in this state, be borne far and wide with its currents.

Out of 25 soundings made up to this date, bottom has been brought up, in greater or smaller quantity, seventeen times. Of this number 10 soundings have been effected with the greased sinker, and 5 with the conical cup.

I have devised, and submitted to Sir Leopold M'Clintock, a modification of the "Clams" which he described to me as having been employed by Sir John Ross many years ago. Instead of clams I have suggested *cups*, closing on hinged levers, and available with the hollow Brooke's sinkers supplied for use on board the 'Bulldog.'

July 13.—Called on the leading residents at Rekiavik, and experienced from them the cordial hospitality for which they have always been remarkable. The name of the ship seemed to afford the little community a standing joke as being peculiarly applicable to "John Boole." It is only to be hoped that their ideas

of our refinement were not based on the grinning demon that passes muster as a figure-head, and vouches for our "fancy" habits by having its neck encircled with a huge saw-toothed collar.

Dr. Hjalthelin, the chief surgeon of the settlement, whose acquaintance I had the pleasure of making today, informs me that Kotla (the volcano which burst into action in the middle of May) is one of the largest in the island. For some weeks prior to the eruption, the wells and springs dried up and several shocks of earthquake were experienced. Towards the end of May, it cast forth vast masses of lava and *ice*, mixed. This is precisely what Sir Charles Lyell states might be expected to take place in the case of the Icelandic volcanos, the cones of which are more or less constantly covered with perpetual snow*,—his conclusion being based on the discovery on Mount Etna, in 1828, by Signor Gemmellaro, of an extensive glacier *over* which had flowed the lava-current. "We may suppose," writes Sir Charles, "that, at the commencement of the eruption, a deep mass of drift-snow had been covered by volcanic sand showered down upon it before the descent of the lava. A dense stratum of this fine dust mixed with scoriæ is well known to be an extremely bad conductor of heat. . . . . Suppose the mass of snow to have been preserved from liquefaction until the lower part of the lava had consolidated, we may then readily conceive that a glacier thus protected would endure as long as the snows of Mont Blanc, unless melted by volcanic heat from below."

In the recent eruption of Kotla these several conditions would seem to have been fully answered. It is well known that the summit of the cone of this mountain was completely encircled with glacier. During the earlier period of the eruption the ejected matter consisted principally of small scoriæ, with immense volumes of dust, by which the atmosphere was darkened. It is therefore highly probable that a considerable layer had time to collect, and thus to protect from immediate disruption the great mass of ice occupying the depression of the crater. On the eruption attaining its height, this mass would be rent asunder, in the first instance, into innumerable blocks of still gigantic proportions; and finally these blocks, melting and being dislodged by the intensity of the temperature, would flow towards the vents and there mingle and be ejected with the general mass of volcanic matter.

* Lyell's 'Principles of Geology,' 1853, p. 413.

During the continuance of the eruption, great sickness and mortality are said to have occurred amongst the inhabitants of the islands and their cattle. Forty thousand sheep perished in the short space of six weeks. Similar results are recorded as having attended previous outbursts. They are referred to, not as secondary results of the phenomena, but as being directly and entirely due to the dissemination of mephitic vapours. Now although the gaseous products of volcanic action are no doubt highly deleterious, I cannot help thinking that an undue amount of direct influence is supposed to attach to them. Leaving out of the question the effect on the animal economy of inhaling minutely pulverized particles of mineral matter of any kind—effects which can be demonstrated too frequently amongst our own manufacturing towns, without having to seek for illustrations in volcanic regions—I think it highly probable that fear and mental depression must be regarded as the mephitic influences most potent in the production of the evils. No more conclusive proof is needed of the wonderful extent to which fear may operate, than the almost universal sensations of "sickness" and "giddiness" said to attend an earthquake. As the shocks rarely last above a minute or two, it is obviously absurd to refer these sensations to any more palpable cause than alarm; and we may readily understand, therefore, how such sensations, if protracted for considerable periods, and aggravated by the intensity of the predisposing cause, may bring about the most alarming or fatal consequences.

CHAPTER II.

LEAVE REKIAVIK.—LIMITATION OF VOLCANIC DEPOSIT.—ITS SUPPOSED CAUSE.—SOUNDINGS.—ABSENCE OF MINUTE ANIMAL LIFE AT SEA-SURFACE.—BROOKE'S APPARATUS.—VALUE OF CAREFUL MICROSCOPIC EXAMINATION OF SOUNDINGS.—UNUSUAL ATMOSPHERIC APPEARANCE.—FIRST GLIMPSE OF GREENLAND.—PACK-ICE AND BERGS.—DEPTH OF SEA BETWEEN ICELAND AND GREENLAND.—GREAT EXTENT OF ICE-PACK.—HEAVY GALES.—GREAT GLACIER.—TALLERT BANK.—UNABLE TO REACH FREDERICKSHAAB.—RAPID DRIFT OF ICE.—SHIP SUDDENLY HEMMED IN.—RETURN TO TALLERT BANK.—FALL IN WITH OUR COLLIER.—RENEWAL OF ATTEMPT TO MAKE FREDERICKSHAAB.—PROCEED TO THE NORTHWARD.—BAAL'S RIVER.—ARRIVAL AT GOODHAAB.

July 15.—Left Rekiavik yesterday forenoon just as the clouds, which had so invidiously hung over the island during nearly the whole period of our stay, began to break and give promise of returning sunshine. But the mists still surrounded the whole of the mountain-ranges, and Iceland faded from our sight much after the same provoking fashion that the Faröes did.

Soundings have been taken at intervals of two hours; and as each one is invariably examined by me the moment it is brought on board, I had rather too much science and too little slumber during the night. Having traced the range of the volcanic deposit to the eastward of the island, it becomes a matter of great interest to find out how far it extends in the direction of Greenland. This I shall now have a double opportunity of doing, as the 'Bulldog' is to return to Rekiavik on her home voyage.

The soundings already taken reveal a very curious fact, namely, that all trace of the fine volcanic mud which constitutes almost the entire mass of the bottom deposit between the longitudes of 14° 40′ and 23° 02′ (the latter representing a point distant about fifteen miles from the western shore we have just left) ceases along a tract of about forty miles. Along this interval it is replaced by rounded basaltic gravel; but at a distance of about sixty miles from land it re-appears, in reduced quantity and a much more comminuted condition, as a slate-coloured mud. From this point the traces grow fainter and fainter, until in long. 27° 33′ they are altogether suspended, the depth of water being 819 fathoms.

as crystal, the sea as unruffled as a mirror; whilst the blue tint presented by both was of an intensity rarely equalled except in subtropical latitudes.

Before us stretched in a long line, extending as far on either side as the eye could reach, the rugged mountain-ranges that hem in the eternal desolation beyond. No gentle slope mingled with the outline of the innumerable icy peaks which stood out against the horizon with an almost terrible distinctness, but everywhere was to be seen the stern grandeur of a scene beside which the snowy ranges of the Himalaya, majestic as they are, would appear subdued into tameness. Between the ridges, the snows of centuries had already filled up the chasms, and hid from view all but the most perpendicular faces of rock. No portion of the shore-line was visible; yet its position and direction could be determined by the differences in character of the fixed and floating ice. From it, to within a short distance of the ship, extended a dense mass of closely aggregated pack-ice, out of the midst of which, at intervals, huge bergs reared up their glistening sides, whilst, floating clear of the pack, detached masses were to be seen whose battered condition plainly told of many an Arctic blast and wave. Some of the bergs were of gigantic size, and exhibited a regularity of form almost unaccountable. Others, again, seemed as if they had been fretted and contorted into every possible shape. The further we advanced, the more numerous the bergs became; and in passing near them we could detect the exquisite colouring of the water-washed portions as contrasted with the virgin whiteness of the upper walls. Such tints of soft blue and green no other hand than Nature's could impart, such contrasts of light and shade where apparently there was no colour, and such contrasts of tint where it was impossible to detect a shadow. But the attempt to describe such a scene is vain. The eye may gaze upon it and admire; but the soul, as if conscious of God's presence, bows down in adoration and is speechless.

The total number of soundings taken between Iceland and the east coast of Greenland was thirty. Assuming the entire distance between the two points to be, in round numbers, 600 miles, this would give an average interval of twenty miles from sounding to sounding. The mid-channel soundings, however, were about fifty miles apart.

The greatest depth, namely 1572 fathoms, was encountered halfway across, the descent being apparently very regular down to that point. As already noted,

all trace of volcanic particles was lost about one-tenth of the distance across, in long. 25° 07′.

The ascent from the deepest recorded sounding (which was in long. 32° 34′) was equally regular up to a point about fifty miles distant from the east coast of Greenland. But here a very sudden and remarkable rise was met with—the depth decreasing from 806 to 227 fathoms in three and a quarter miles; that is, at a rate of 1050 feet per mile.

The greatest dip on the mid-Atlantic route occurred, as is well known, near the Irish coast. It was at the rate of 720 feet per mile. The respective ratios of these two great dips are, as 1 to 5, and 1 to 6, and represent angles of eleven and nine degrees.

In attempting to dredge today in 108 fathoms water, whilst a sounding was going on, my dredge got foul of rock at the bottom and was lost. This is a serious accident, inasmuch as it was the only apparatus of the kind I was enabled to procure before leaving England. Had it been made of gold, instead of the baser metal, the loss could hardly have been more keenly felt at the present moment.

I have already alluded to the uncertainty of action in Brooke's sounding-machines. But the experience derived from some of our recent soundings suggests doubts in my mind as to whether the results obtained by any of the methods of sounding hitherto employed can be relied on as affording a correct estimate of the character of the sea-bed.

On the occasion of the dredge being lost, it was dropped over the stern, whilst the sounding with the conical cup was being conducted in the usual place, namely over the bows. The cup came up half full of grey mud, pieces of granitic and felspathic rock, varying in size from a quarter of an inch to an inch, and some fragments of a delicate coral. From indications present on the pieces of rock, it was perfectly clear that they were resting on the bottom as gravel or shingle, and that they were not broken off by the machine from the strata forming it. On the other hand, it was equally certain that either exposed rocky strata or very large detached masses of rock constituted the bottom, inasmuch as the strain caused by the fouling of the dredge was sufficient to snap asunder the perfectly new deep-sea-line attached to it, and which was capable of bearing a weight of several hundred pounds.

Our first day amongst the ice terminated with a sunset worthy of the majestic mountain scenery over which it shed its gorgeously-tinted rays. If the old saw be correct, we may look out for "dirty" weather tomorrow.

July 20.—It blew hard during the night; and but for the pack-ice, which befriended us, we must have had a far more boisterous sea. For the first time since approaching the Faröe Islands, the endless day has been interrupted by a couple of hours of twilight, during which a few stars ventured out like modest virgins, and then hastily retreated as if in alarm at their own temerity. During the day and so long as the air was still, the temperature, although bracing, did not feel perceptibly lower than that of a fine day in November in our own latitudes. But as we neared Cape Farewell, the air began to feel bitterly piercing, the sky was overcast, and we were so closely surrounded by ice that the ship had to be put considerably to the southward of her course.

We are now well out to sea again, out of sight of land, and with ice all round. After proceeding to the northward till about 9 A.M., the pack became too dense to admit of our advancing, and accordingly the 'Bulldog' is compelled to retrace her steps until clear water shows itself.

July 22.—The ship is now heading to the north-westward at the entrance to Davis Straits, in order to get clear of the pack, and is to continue on this course till abreast of Frederickshaab, a Danish settlement on the west coast of Greenland, about 180 miles from Cape Farewell, where a vessel has been directed to precede her with a supply of coal. The barometer has been steadily falling during the whole night, and now stands at 29·17. A heavy gale blowing.

July 23.—The ship "lying to" all night under storm jib and close-reefed topsail. There is a tremendous sea running, and in it the 'Bulldog' wallows to her heart's content. Everything in my cabin adrift, and apparently intent on mischief. As any endeavour to restore order in such a turmoil would only be to establish a fresh point of "departure," I must rest content to let the riot continue for the present. Writing, under these circumstances, not only demands some skill in equitation, but has to be done by catching a propitious interval between each surge—much in the same fashion that the engineer uses the oil-can in those parts of the machine near which, were his hand to remain an instant too long, it would be crushed into mincemeat.

July 24.—Land in sight all the forenoon. At 5 P.M. we were off the "Ice Blink," or Great Glacier, about thirty miles to the northward of Frederickshaab. This gigantic mass of ice is said to be twelve miles in diameter, although, from the circumstance of its forming a curve, it appears considerably less. On either flank, the lofty mountain-ranges slope down and form the broad valley on which the glacier rests. Far back in the distance some bold peaks rise suddenly from the general mass, and mark its boundary in that direction; whilst stretching across an arc of twenty degrees, and at a probable distance of not less than thirty miles, the still unbroken contour of the mighty glacier cuts the horizon.

But, withal, the scene is tame, and, compared with that observable on the eastern coast, almost uninteresting. The long regular sweep of the surface of the glacier is unbroken save by the innumerable little channels worn into it by the melting of the upper layer during the short northern summers, and, instead of presenting the pure whiteness of the peaks on either side, is stained and muddy from the deposits that have taken place upon it. Seen from a distance of ten or fifteen miles, the angle of inclination appears exceedingly small; and along the shore-line the vast mass descends so gradually as to afford no indication of the point at which it terminates and the land-ice begins. According to Crantz (Hist. Greenland, translated from the Danish: London, 1820, p. 5), "The "points of land, which run out a great way into the sea on both sides, consist "of banks of sand so fine and light that, when agitated by the slightest breeze, it "darkens the air like a cloud, and fills the eyes and mouth of all who approach "within eight leagues of the shore." This accounts for the peculiar colour of the surface of the glacier; but it is somewhat remarkable that, although the narrator of the above fact visited the "Ice Blink" at precisely the same period of the year as we did, no other trace of the presence of this dust-bank was observable.

An extensive shoal, called the "Tallert bank," reaches out to sea for many miles in front of the great glacier. I was extremely desirous of ascertaining the character of the deposit constituting this bank; but the state of the weather and ice afforded no opportunity. This is the more to be regretted, as, from the appearance and form of the glacier, the fact of its never "calving" (that is, giving off bergs), and the existence of an extensive shoal, I am inclined to believe that the glacier now under notice covers a large river which takes its rise in the far interior, and debouches below low-water mark, bringing with it

the detritus to build up the bank. Under no other set of conditions does it seem possible that such a shoal should form. The fact of other glaciers both on this and the east coast giving off bergs is of itself proof of the presence of deep water, inasmuch as the stranding of masses of sufficient size to offer resistance to the downward progress of the glacier itself would inevitably be overcome in time by the accumulated pressure. The first operation of this pressure would be to heap up a pile of gigantic bergs. Gradually it would overcome the resistance of these and hurl them onwards, ploughing out chasms in the sea-bottom, and eventually creating channels of sufficient depth to float the detached masses subsequently given off. By degrees the boundary-walls of these channels would be broken up and deposit their silt along the deepest portions. Again obstruction would take place by the grounding of the bergs. Again the channels would be cleared. Again the silt would be deposited, but in diminished quantity,—until at last, under the combined and long-continued repetition of these causes, the depth of the sea-bed would become sufficient to permit the unimpeded descent and advance of the newly-detached bergs. If we bear in mind that these ice-masses do not glide into the sea from their parent glacier, like Naiads gliding into a crystal lake, but plunge headlong with a crash which raises the water around into a perfect tempest, extending for several miles, and that the detached mass does not recover from its drunken gyrations for days after leaving the land, we shall be able perhaps to form some estimate of the stupendous force that an accumulation of these masses would engender.

In Crantz's narrative already referred to, he gives an extract from a communication made to him by an old Danish factor who had resided many years at Frederickshaab. Speaking of the difficulty of accounting for the immense quantities of ice discharged from Disco Bay, the narrator says, "I received "some explanation of this difficulty from a journey I made with some Green- "landers along the 'Ice Blink Bay' as high up into the interior as any Green- "lander had ventured. I then discovered that, though nothing but firm land "coated with ice appears seaward, there may still be open water on the land side. "I also learned the manner in which the fragments of ice are carried down into "the sea by the current, *under the solid surface.* When and how the mouth of "the bay was blocked up, is unknown. Probably, during a long season of calm "weather attended with severe frost, in the middle of winter, the drift-ice may

"have continued stationary at the mouth of the fiorde, and being exposed in spring "to an alternation of thaw and frost, have been consolidated in a mass firm enough "to resist the summer's warmth, and the action of the winds and current. The "frozen snow accumulating for ages has swollen this mass to so huge a bulk, that "the narrow arches through which the stream impetuously rushes are in many "places 20 fathom high. The pieces of ice yearly precipitated from the moun- "tains into the open bay are hurried down by the stream upon this icy bridge. "The smaller fragments float through; the larger dash against it until they are "broken into pieces small enough to pass through also*."

Now, although the character of the glacier must have undergone great modification since the period to which the above account refers—no less than 104 years ago—inasmuch as its sea-margin does not rise to half the height to which the arches are stated to have reached, there is quite sufficient evidence to shŏw that a vast subglacial efflux of water must have been present at that date.

July 25.—After steaming slowly to the southward all night, it is found that the passage into Frederickshaab is impracticable. The whole coast-line is blocked up with an impenetrable barrier of ice extending for many miles out to sea. It is usual for the coast-ice to begin to disappear considerably before this period; and as the movement takes place from the northward, it is but too probable that the settlements to the southward, namely Julianshaab and Nenortalik, are equally unapproachable. The collier therefore can hardly have reached either of these places. I believe we have one week's supply of coal left. The barometer is again falling rapidly, and already it is blowing a gale. So once more we are off to sea. Towards evening steam shut off, and ship under sail only.

Besides the main body of the pack hemming in the coast as a long unbroken barrier, a number of bergs of very large size are to be seen on every side. These vary in height from 50 to 150 feet or even more. One appeared to be about 200 yards in length. The detached pieces of pack generally indicate a thickness of from 15 to 20 feet, whilst in diameter they are at times as much as 100 yards. A curious appearance is observable in some of the bergs. As already mentioned, the entire mass above water is generally of the purest whiteness, there being little or no transparency visible until within a few feet of the line of floatation. But in some bergs delicate yet well-defined lines may be seen, of a rich ultra-

* Crantz, 'History of Greenland,' p. 19.

marine colour, traversing the faces from side to side or from top to bottom. At a little distance these lines look like fissures; and so in reality they are, although completely filled up with transparent ice, which contrasts strongly with the pure whiteness of the body of the berg. It is probable that these fissures have occurred prior to the separation of the berg from the parent glacier, and that the transparent streaks of ice are due to the infiltration and congelation of fresh water which has flowed into them; for, had they occurred subsequently to the separation of the bergs, the split portions must have fallen asunder. The nature of the blue streak was clearly exhibited in a berg the nearest face of which appeared to have been recently split off. In this case the summit of the mass was somewhat concave, or rather had been concave, before the face alluded to fell asunder from it; and towards the central portion of its upper edge was to be seen the sectional view of a trough, from the base of which the blue streak extended down to the water's edge, both the trough and the fissure proceeding from it being filled up with a beautiful clear blue vein of ice. Here, then, it is evident that the infiltration of water into the fissure, and the trough-like cavity from whence it sprung, were due to the thawing of the upper surface of the berg.

July 27.—There is something singularly deceitful in these northern summers. For a few hours last evening the sky shook off the foggy mantle it had assumed the day before and gave token of returning sunshine. The wind lulled almost to a calm, and with it the sea. But it was only to take breath and recover their energies for another hubbub. The glass fell rapidly after midnight; and by 6 A.M. the gale was blowing as fiercely as ever from south-west, the quarter of all others the most certain to accumulate more drift-ice along the coast, and impact it into a denser barrier than ever.

Last evening, the moment the state of the sea admitted, I let down my surface-nets; but, with the exception of the common forms of *Entomostraca*, some ciliograde Medusæ and an Annelid closely allied to *Tomopteris* (Esch.) (the *Johnstonella* of Gosse), I captured nothing.

July 31.—The weather having moderated somewhat, yesterday afternoon the ship started under steam once more for Frederickshaab. The scattered state of the ice through which we passed this morning induced a hope that the coast might now be sufficiently clear to allow of our entrance. But we are doomed to disappointment; for after forcing our way, in a dense fog, through many miles

of drifting ice, we sighted Little Vardoe (the island lying a few miles seaward of the settlement), and found any nearer approach as impracticable as before. It is evident, therefore, that instead of the vast fields of drifting ice through which we have had to thread our way being the dispersed remnant of the pack previously blocking up the coast-line, they were fresh reinforcements brought up by the strong south-westerly gales. In ordinary seasons the current from Cape Farewell is of sufficient strength to keep the channel between Little Vardoe and the mainland clear of ice, even when the rest of the coast is hemmed in. It is evident, therefore, that exceptional influences are in operation this year.

During a sounding taken at 2 P.M. in 100 fathoms, the rate of this current was made apparent by the rapid manner in which the 'Bulldog' drifted towards an immense grounded berg, in order to escape collision with which, the engines had to be backed.

The berg in question was about 120 feet in height. As the ship passed within a hundred yards of it, I could perceive that, from the water-line, the mass diminished rapidly in diameter and sloped upwards at a considerable angle on all sides, whilst immediately below the surface it spread out horizontally for many yards.

I am indebted to the kindness of Mr. Roughton, the chief engineer of the 'Bulldog,' for having replaced my dredge. It has been on its first voyage of discovery, and brought up some interesting specimens of Corals, Polyzoa, and Ascidians,—the latter presenting the velvety tinting of a ripe peach, some of the former so delicate and fragile as to demand the most careful handling; and yet every inch of the sea-bed on which they rest must now and then be ruthlessly ploughed up and crushed beneath the icy mountains that traverse these waters!

Again the 'Bulldog' turns her head seawards, but under sail only, inasmuch as it is more than ever imperative to economize the little remaining stock of coal on board. Passed through immense quantities of ice and saw some gigantic bergs. About fifty miles from land, one of these, at least 180 feet high, was stranded, whilst the surface-current set so strongly towards it that it brought up a vast compact field a distance of two miles in half an hour. The terrific crashing of this moving mass was distinctly audible at a distance of three miles. Notwithstanding the tendency of a bitterly cold Arctic drizzle to strangle every spark of sentiment in its infancy, "imagination bodied forth the forms of things unknown," and

I saw before me a superhuman host rushing on to the assault with a yell that might make hell tremble, whilst a beleaguered garrison, conscious of the impregnability of its position, awaited the assault in stern and silent defiance.

At this stage of the melodrama, the fog overcame both imagination and reality, and the fortune of the day remains a mystery.

In the evening the ship was suddenly hemmed in by ice; and in order to extricate her from this perilous position, she had to make a "stern board." Of course it was admirably managed, and in a few minutes we were again in clear water.

Aug. 1.—Fine weather for once. Sounded for depth, which was found to be 700 fathoms. Lat. 62° 3′, long. 51° 10′.

Aug. 3.—Stood in towards the land, making the Tallert bank again, immediately off the Great Glacier. The day was beautifully fine, and gave us an opportunity of forming an estimate of the state of the ice. The pack seems much broken up, and is taking a north-westerly course seawards the wind being off shore. In a northerly direction the ice does not seem to extend beyond half-a-dozen miles. Inshore there is still a considerable quantity; but, from the heavy crushing roar caused by the pressure of the masses against each other, it seems probable that the whole pack is commencing to move away. The sound referred to is unlike any other I have ever heard, inasmuch as it seems to proceed equally from the entire coast-line within view, and, although loud and distinct, conveys the impression of being felt rather than heard.

The Glacier looks as undemonstrative as ever, and grand in its stolidity.

The pack is reported to extend southwards as far as the eye can reach; but, on our skirting its well-defined margin for some miles, the body of the ice is observed turning off seawards about halfway between us and Frederickshaab. Already it stretches out from land some twelve or fifteen miles. There are "lanes" and patches of clear water to be seen within the pack; but none of these are of a nature to warrant the attempt to force a passage through them—at all events not in a paddle-ship.

In the afternoon a brig was reported in sight, some fifteen miles off, standing to the southward. She proved to be our collier. Her master states that he arrived off Frederickshaab on the 18th of last month, but, a terrific gale coming on, he had to run out to sea again, and was eventually driven so far up to the northward that he has only now been able to effect his return.

Aug. 4.—Once more an unsuccessful effort has been made to reach Frederickshaab, the entire coast being still blocked up with an impenetrable barrier of ice. The 'Bulldog's' head is therefore turned northward, and, with the 'Cicerone' in tow, she goes in quest of a more hospitable port higher up Davis Straits.

Aug. 5.—We passed through a very large quantity of pack-ice yesterday, and met with some unavoidable concussions, but no serious injury. The day was tolerably fine, and afforded us an opportunity of seeing several magnificent peaks and glaciers on the coast. Although none of the latter are comparable, in point of extent, with the great "Ice Blink" near Frederickshaab, they far outstrip it in scenic grandeur. In one instance, the abruptly terminated face of the glacier clearly indicated the recent projection of several bergs.

It rained all night. At an early hour the 'Bulldog' was close in shore. But the sudden fall of the barometer, and the advent of a heavy swell from the southward, rendered it necessary to run out to sea without a moment's delay. By 9 A.M. the wind had already increased to a gale. The 'Cicerone' was being fairly dragged through the seas, which swept her deck from stem to stern. The strain becoming too great, the hawser parted. For a few moments the little vessel staggered, as if in hesitation whether she should go down head first or capsize. But she was too skilfully handled to yield even in the presence of such danger. In the twinkling of an eye a close-reefed topsail was set, and under it and a jib, which had providentially been hoisted before the tow-rope gave way, the gallant craft dashed off to windward and was soon lost to view in the distance.

Aug. 7.—Yesterday forenoon, the gale having moderated, the 'Bulldog' stood in towards land, and made it some miles to the northward of Baal's River. This morning she steamed down along the outer margin of the innumerable rocky islets that gird the coast, and arrived at the mouth of the inlet about 10 A.M., escorted by a small fleet of Esquimaux kayaks.

Although there was less ice along the portion of the coast we had traversed to the northward than had been met with in the direction of Frederickshaab, the entire surface of Baal's River and the fiords branching off from it, was covered with such a dense mass that it was with great difficulty, and only under the exercise of the utmost skill, that a passage through it was effected. About 4 P.M. the 'Bulldog's' anchor dropped in the harbour of Goodhaab.

CHAPTER III.

HARBOUR AT GOODHAAB. — BESET IN THE ICE. — AMERICAN ENTERPRISE. — DANISH SETTLEMENTS.—SEVERITY OF SEASON.—DEPTH OF FIORDS.—DREDGING UNDER DIFFICULTIES.—METHOD OF DETERMINING IMMERSION OF ICE.—BOULDERS.—MOUNTAIN TARN.—MICROSCOPIC ALGÆ.—ESQUIMAUX AND THEIR KAYAKS. — OOMIAKS. — DEPARTURE FROM GOODHAAB. — FREDERICKSHAAB AGAIN.—CAPE DESOLATION.—ICE AND ICEBERGS.—SOUNDINGS ACROSS DAVIS STRAITS.—ANCHOR IN HAMILTON INLET.

After being tempest-tossed for nearly three weeks in the midst of an ice-covered sea, it is pleasant to find ourselves, in company with four other vessels, resting placidly in a land-locked bay, over which the Arctic blasts may blow their fiercest, but whose surface they would find it difficult to arouse into any greater commotion than a ripple. On three sides it is encompassed by steep hills rising up to a height of several hundred feet, with deep water extending almost to their bases. On the fourth, a long spit of rock stretches to the westward and overlaps a bluff headland that closes in the harbour from the fiord outside. Away to the southward, the peaks of "Hiorte Tok," or the "Stag's-horn" mountain, rise above the boundary-walls of our anchorage, whilst an intermediate range sweeps round the eastern margin of the broad fiord, from which it is separated by the spit already referred to.

The other vessels consist of a couple of Danish barks of about six hundred tons burden, come in here for shelter until the state of the ice admits of their going into a southern port to load with cryolite; a smart-looking American schooner, carrying a living cargo of fifty students of Williams' College, Massachusetts, bound to these parts on a scientific excursion, under the superintendence of Professor Chadbourne; and lastly our collier brig.

The American was strenuously endeavouring to beat up the channel as we steamed in, but was baffled by the immense quantity of ice about. At the request of her Captain, who came on board, she was towed in to the anchorage by the 'Bulldog.'

Aug. 8.—The scene around us today is both unexpected and interesting.

We are completely beset in the ice-pack, which has been streaming in uninterruptedly from seawards ever since our arrival, and may be seen from the masthead still pouring in at the entrance to Baal's River. In the harbour the masses are crowded together in such close order as to render it impossible even for a kayak to move amongst them; whilst the constant rolling over of pieces here and there, owing to the crushing pressure to which they are subject, effectually bars any attempt at passing to and fro on foot.

The whole of the ice appears similar in character to that by which we have been so hampered lower down the coast, and is of too great thickness to have been formed in the fiords on this side of Greenland. The pieces vary from 3 feet in superficial diameter to 40 or more. But in thickness above the water-line there seems to be much greater uniformity, the range being from 2 to 6 feet. Interspersed amongst this pack-ice are a few small bergs, not rising above 10 or 12 feet from the surface, and in all probability fragments of larger masses.

Strange to say, although the temperature of the water at the surface is only a few degrees above freezing-point, wherever a clear space of a few inches intervenes between the pieces of ice, delicately tinted Medusæ and glistening Beroidæ may be seen struggling upwards from the depths to bask in the sunshine of which they are being so rudely deprived,—whilst numbers of mosquitos, active enough to have emerged from a tropical forest, buzz through the air and evince their sense of its warmth by bloodthirsty attacks on all new comers. Nature for a time seems to search for contrasts. Above, an Italian sky; below, an Arctic sea; as if Summer had stolen away from the soft South to smile on Winter in his grim domain.

Aug. 10.—The partial clearing of the ice today has enabled me to reach the 'Nautilus' and make the acquaintance of Professor Chadbourne, from whom I had received a very polite message. I learn from him that the expedition, of which he is the director, is a private one, the entire expenses, even to the chartering the schooner, being liquidated by the students or their friends—the object in view being to teach them how to observe and collect specimens in the various departments of Natural History. The 'Nautilus' left Thomaston on the 27th of June, and, after dropping a small party, *en route*, at Labrador, reached the Greenland coast, off Julianshaab, the same day that the 'Cicerone' reached the neighbourhood of Frederickshaab, and experienced the full force of the gale

alluded to by the master of the latter vessel. It may be recollected that on the east coast of Greenland, in almost the same latitude, the 'Bulldog' experienced calm weather on the eclipse day, and that it was not until she had rounded Cape Farewell and emerged from the shelter of the land that the south-westerly storms burst upon her.

Professor Chadbourne informs me that on the morning of the 18th of July the 'Nautilus,' in endeavouring to make the land off Frederickshaab, met with an immense belt of pack-ice a hundred miles from shore, from which she had barely time to escape when the gale suddenly increased to a perfect hurricane. Running northward before it, in a couple of days the schooner was enabled to round the advanced extremity of the pack, and to anchor in a little harbour in the vicinity of Sukkertoppen, a small settlement about eighty miles due north of Goodhaab. But for the absolute necessity of obtaining the supply of coal directed to await us at Frederickshaab, the 'Bulldog' might therefore have been comfortably ensconced at a like early date.

There are two small stations here, situated near the north-western angle of a rather low peninsula, of nearly a mile in breadth, which abuts on Baal's River, and separates our present harbour from it to the northward. At one of these, namely Hernhutt, the Moravian Missionaries reside, whose predecessors, more than a hundred years ago, established the first colony in the country. At the other, Goodhaab itself, the superintendent of South Greenland (Dr. Rink) and the principal merchants are located. On the eastern side the little peninsula is united with the mainland by a series of hillocks, which gradually increase in height as they approach and sweep round the inner margin of our anchorage; whilst along the shore-line it is protected, by a natural rampart of gneiss-rock, from the waters of Baal's River and the adjacent fiord, which would otherwise inundate it.

The Danish residents inform me that such a severe season has been unknown in Greenland for thirty years, and that the quantity of ice far surpasses that usually met with. On the other hand, it is a remarkable circumstance that the quantity of drift-wood brought round with the ice from Cape Farewell is far below that met with in average seasons. This can only be accounted for on the supposition that the range of the Arctic current, as it sweeps across from Nova Zembla and Spitzbergen towards East Greenland, has been so far extended to

the southward as to overpower and deflect that portion of the stream which bears the drift-timber across.

Aug. 12.—Whatever may be the aspect of Greenland in its winter garb, or under lowering skies, it is a very enjoyable place on a bright day in August. Notwithstanding the scanty nature of the vegetation, there is quite enough verdure observable to soften the asperities of the landscape, whilst the brilliant sun and pure atmosphere impart a degree of warmth to its colouring that is heightened, instead of being destroyed, by the cold whiteness of the ice-covered fiords.

The quantity of ice is somewhat less today; but it fluctuates so rapidly as it happens to be influenced either by the wind or tide, that it is impossible to foretell one hour what may be the state of the fiords the next. Yesterday the pack streamed in so suddenly, that a large party of the Danish residents who had come round from the colony, by boat, to visit the ship, were obliged to make their way home in the dark, across a mile of heavy swamp.

The temperature in the middle of the day is producing marked effects on the ice. On every side the ear catches the sound of the melted drops as they trickle from the projecting ledges into the water. Many of the pieces seem already to be honey-combed, and break up when subjected to pressure by the surrounding masses, the immediate alteration in their centres of gravity causing them to turn over and set the whole of the neighbouring pieces in motion. This is probably the reason why disintegration, when it has once commenced, goes on so rapidly, and even continues for some time after the midday heat is over; for the temperature of the air does not rise above 64° Fahr., and the water of the fiord is too cold to admit of the hand being plunged in it for many minutes without causing acute pain.

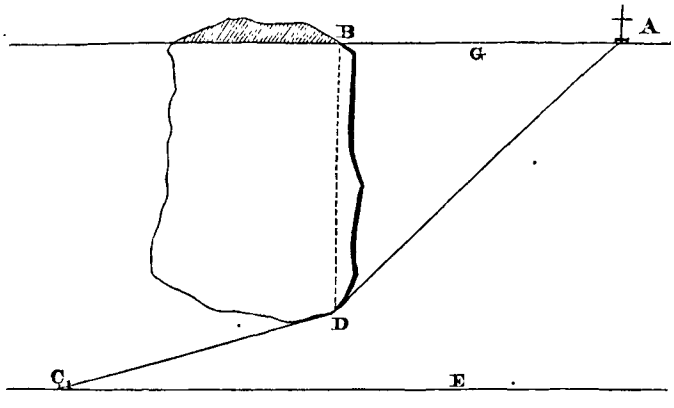
The great depth of the fiords constitutes one of their most striking characteristics. During my attempts to dredge, I rarely met with less than 20 fathoms close to the shore, whilst as the centre of the fiords was approached it ranged from that up to 150 fathoms. At one portion of the large bay stretching across from Hernhutt towards the sea the dredge was let go in 200 fathoms, and from that great depth brought up a number of Sea Urchins (*Echinus Sphæra*).

But the depth was by no means the only obstacle to the use of the dredge. The powerful tide, the quantities of drifting ice, and the nature of the bottom,

which seems to consist almost entirely of boulders, all tended to render it both tedious and hazardous; and on more than one occasion I had cause to be thankful that, during my endeavours to clear the dredging-line from the large masses of ice that continually drifted against and fouled it, their sudden plunging over did not send my small crew and myself on a sounding expedition for which we were but ill prepared.

The following method of computing the ratio of immersion and elevation of floating ice-masses suggested itself to me on one occasion of the line becoming entangled. As I am not aware that any practical plan has heretofore been devised for ascertaining the point, I may perhaps be permitted to illustrate it by a diagram.

Suppose BD to represent a mass of floating ice; G, the water-line; E, the bed of the sea; AC, a grappling iron or deep-sea lead and line, impinging at D against the base of the ice-mass; and A a boat or ship.



Assuming the imaginary line BD to be perpendicular, and that we can measure the distance from A to B, it is obvious that we have two angles DBA and DAB, and a base-line AB, from which we can at once deduce the length of the side BD. But all calculation may be avoided by the simple expedient of moving the boat at A until the angle DAB equals 45°,—the base-line AB being then equal to BD, which represents the immersion of the mass. Lastly, the height of the portion above water being measured with an oar or boat-hook, the ratio may be calculated.

Availing myself of this plan, I found that for every foot above water, in such masses as maintained nearly the same proportions above and below the surface, there was never less than 14 feet below the water-line, and generally as much as 16. As I have already stated, the whole of the ice met with at Goodhaab is precisely similar in appearance and character to that we fell in with at sea, and cannot be regarded as the freshwater ice, which is said to be much more com-

pact and clear in its texture, and to be heavier than the ordinary pack-ice, bulk for bulk,—the difference I have referred to, namely in the ratio between 1 to 14 and 1 to 16, being, I conceive, wholly attributable to accidental differences in the solid contents of the submerged and exposed portions. Thus, in a small berg which was stranded at the head of one of the fiords, I found the ratio of submergence to elevation to be only 7 to 1; but the cause of this decreased ratio was manifest, inasmuch as the portion above water rose up to an angular peak, whereas from the water-line, as deep as the eye could penetrate into the clear water, the berg retained its dimensions. As it was aground close to the shore, I was enabled to measure the height of its summit by scrambling up the hill-side adjoining, and I found it to be a little above 40 feet. The water immediately around it, as measured by a plummet, was somewhat more than 50 fathoms. At the period of the tide at which I inspected it, the line of floatation was 6 feet from the surface of the fiord. But it was parallel to it, and it is therefore unlikely that the berg could have been resting on a boulder or rock elevated above the general level of the bottom. Assuming, then, as the appearances warrant, that the solid contents of the 40 feet above water were equal to half the solid contents of a like number of feet below water, we should have a ratio of 1 to 15, or the mean of that established by actual measurement.

I have alluded to the presence of boulders in the fiords adjoining the anchorage at Goodhaab. From the clearness and stillness of the water, it was often possible to observe the bottom, near the shore-line, at considerable depths; and I was sorely puzzled to account for the smooth rounded look of the greater portion of these stones. It was evident these could not have been subject to the action of waves, from the depth at which they lay. There was no glacier in the vicinity to which their presence and figure might have been attributable. Nor did it seem probable that such a uniform distribution could have been effected by icebergs or ordinary drift-ice which had brought them from distant localities. On examining the character of those occurring near low-water mark, I found it corresponded with the rock-formation of which the surrounding heights was composed. But as the same kind of formation is said to prevail along the greater portion of the west coast of Greenland, both to the north and south, it offered no satisfactory explanation as to the origin of the boulders in the present locality.

At the south-eastern angle of the large fiord to the southward of the anchorage, I found not only that these boulders were congregated together in unusually large quantity, but that they formed a sort of moraine, extending along a valley which ascended for about 2000 feet up the mountain. Following this valley to its crest, I arrived at a tarn of nearly a mile in diameter, occupying an amphitheatre the whole of which, with the exception of the part next to the fiord, was bounded by a precipitous escarpment. The height of this could not have been less than 1000 feet. Its face seemed to be cut up into innumerable channels, as if by the overflow of torrents at its upper margin; but water was only streaming down a few of these, and apparently in no great volume. The margin of the tarn was perfectly level all round, and occupied the entire area of the amphitheatre thus formed. As the water was only about a foot and a half in depth, and its temperature, comparatively speaking, warm from the absence of ice, I waded in for some distance, and found that the bed consisted of nothing but an accumulation of boulders, all more or less perfectly rounded. From the appearance of the valley, the remains in it of enormous boulders of quartz-rock, some of which are 15 feet in diameter, and the polished and, in places, furrowed surfaces of the schistose rock which constitutes the bed of the valley itself, it would seem probable that this had once been occupied by a glacier, and that the masses of rock detached from the escarpment on the melting of the snows are worn down into their present form during their transit across the flat bed of the tarn and ultimately carried along by the torrents to the fiord below. Once arrived there, and deposited in a gradual slope, the ice formed in the winter would bear them away and distribute them over the bottom.

A curious corroboration of the perpetual grinding to which the boulders in the tarn are subject is derived from the fact that not a trace of any of those microscopic algæ, or lower animal forms, with which the surfaces of smooth stones are invariably encrusted, even in streams running with considerable velocity, could be scraped off with a knife; whereas in some small rocky pools situated on the slopes of the lower hills, I met not only with Confervæ, but Diatoms growing in great profusion, and between twenty and thirty species of Desmidiaceæ.

Aug. 13.—From infancy the Esquimaux is taught to regard the sea as his special domain, and to look to it as his great store-house for food, for clothing, and, in short, for everything that is absolutely essential to his existence.

His kayak combines symmetry of shape with extreme lightness and strength: it is formed of seal-skin stretched over a framework made partly of drift pine-wood and partly of whalebone. His hunting and fishing implements are constructed of the same material. Every article of his dress, his tent, the window of his hut, the substance which yields him light and warmth in the long Arctic winter, and, in a great measure, his food are products of the sea. Every particle of wood he uses comes from the same source. We might, therefore, naturally expect to find him an adept in the management of his canoe; but I was certainly unprepared for a feat which some of the Exquimaux performed this morning alongside the ship, where the partial clearing away of the ice had left sufficient space for them to manœuvre. It consisted in turning a complete somersault sideways, kayak and all; the occupant of the kayak swaying his body to and fro laterally, with the arms stretched out so as to poise the paddle in front of the chest, until sufficient momentum was engendered; and then capsizing, as it were, on one side and coming up on the other. One poor bleareyed old man went through this performance at least a dozen times, receiving as his recompense that greatest of all luxuries to an Esquimaux, a pound or two of ship's biscuit and a little tobacco.

The oomiak, like the kayak, is formed of seal-skin, stretched over a wooden and whalebone framework, but, instead of being contrived to hold only one person, is capable of carrying from twelve to twenty. It varies in length from 25 to 35 feet, and in breadth from 4 to 5 feet, and is invariably rowed by women. As might be supposed, boats formed of material so readily torn or pierced by ice or rock must be somewhat liable to accident whilst traversing the Greenland coasts for several hundred miles, as they constantly do. But the tendency to leakage is provided against in a curious and highly characteristic manner, namely, by constantly keeping at hand several large pieces of seal- or whale-blubber; so that, the moment a rent occurs, a proportionally sized lump of this substance may at once be forced into the aperture. Both owing to its oily nature and its great elasticity, it is perhaps more admirably adapted than any other material that could have been hit upon to effect the required object.

Aug. 15.—The ice having materially diminished in quantity, both in Baal's River and the fiords on this side of it, and our supply of coal having been taken on board, at 8 P.M. yesterday, the 'Bulldog' left the harbour in order to proceed

to sea. She had hardly started, however, when a thick fog rolled down from the heights and compelled her to drop anchor again at the head of the nearest fiord. At an early hour this morning she once more got under way, and, taking the 'Nautilus' in tow until clear of the islands at the entrance of Baal's River, commenced her voyage to the southward.

During the day we passed between some extensive fields of ice, and at times approached close to the coast. But, on arriving abreast of Frederickshaab, it became manifest that our chance of effecting a passage into the harbour was as remote as ever. For the fourth time we found the entrance barred against us; and for the fourth time the 'Bulldog' is ploughing her way out to sea, with a heavy south-westerly gale blowing.

Aug. 16.—The gale abated this morning; and at noon we were steering towards Julianshaab, a Danish settlement about midway between Frederickshaab and Cape Farewell,—Cape Desolation bearing south-east, and distant about a hundred miles.

The surface of the sea was more or less covered by extensive fields of fragmentary ice in the last stage of decay. Some of these fields were two or three miles in diameter,—the close aggregation of the pieces being due, in all probability, to the long rolling swell and calm which have set in since the gale moderated. My attention was arrested by the continuous crackling sound audible on all sides as the ship traversed these ice-fields, and which resembled the pattering of heavy rain-drops when falling on sheets of metal. Being quite unable to account for the peculiar character of the sounds by the mere collision of such small masses—for they rarely exceeded 6 or 8 inches in thickness, whilst the greater number were considerably under that size—I procured a bucketful, and, to my surprise, discovered that they were produced by the ice being in such a state of decay that a very slight blow sufficed to break it up still further, and to explode the minute air-chambers in its substance. Some of the pieces were full of these air-chambers, besides being riddled by tubular cavities exactly resembling the holes bored by *Teredo*, sometimes open at either end, sometimes only at one, but never closed at both. The air-chambers, on the other hand, could be seen distinctly in the substance of the ice as closed cavities, like the little air-bubbles often seen in glass.

I conceive that the rapid disappearance of the pack-ice from the west coast

of Greenland is, in a great measure, attributable to the agency exerted by these cavities in breaking up the masses after the process of thawing or, in other words, ice-decay has proceeded to a certain extent. The growth of ice, as is well known, takes place from above downwards: that is to say, the uppermost layer of a frozen surface is the one which was first generated; the same rule holds good with each subsequently formed layer in relation to those below it again; so that the undermost layer is necessarily the one last produced.

Under the influence of winds and waves, a certain quantity of the atmospheric air with which sea-water is invariably charged is constantly being given off again at the surface. The moment a pellicle of ice forms, it precludes the escape of the air-bubbles, and they become frozen into the ice-mass at a time when, from the reduction in temperature, they are very much reduced in volume.

In the case of icebergs the same result takes place, although in a somewhat different manner. Berg-ice, as is well known, is produced on land, and is, in reality, snow solidified under enormous pressure. Here, then, the case is reversed, the undermost layer being the oldest of the series. Consequently the air entangled in the snow-flakes, also at a time when reduced in volume by cold, becomes more and more compressed, whilst the substance within which it is imprisoned becomes more and more solidified. Now the very cause that brings about the decay of ice, namely, elevation of temperature, produces the expansion of the air contained in the chambers; and thus the expansive force operates precisely at the moment when it has the slightest amount of resistance to overcome. Hence the little detonations, and the disruption of the ice-masses that attends them.

The tubular cavities proceed from the disruption of the air-cells on the under surface of ice-masses, whenever the temperature of the water rises sufficiently to produce thaw. The air-bubble, unable to escape, continues to press upwards, whilst the access of the water to the interior of the chamber gradually eats away the walls. A vertical tube is the result, the upper portion of which is occupied by the now somewhat expanded air-bubble, whilst the lower portion is filled with water. This boring goes on until the water within the tube reaches the level of the surrounding surface, but there it necessarily stops; and we can accordingly account for the uniform honeycomb character so constantly presented on one surface of ice-masses. When, by collision or force of any kind, ice is

broken up in a line parallel to its line of floatation, these tubes sometimes penetrate through and through; and in this state I found nearly the whole of the smaller pieces today.

The occurrence of a great number of these cavities at the base of small pieces of ice must also tend materially to influence their submergence, and cause them to tilt over, should the boring action proceed more rapidly in one direction than another.

I have been induced to dwell on this subject, inasmuch as the extremely rapid disappearance of the ice that besets the coast of Greenland for certain months of the year has been regarded either as wholly inexplicable, or has been attributed to a cause which involves an impossibility, namely, its sinking to the bottom *en masse*. From what took place during the last few days of our stay at Goodhaab, coupled with the remarkable condition of the ice just described, there can hardly be a doubt that during a very brief continuance of sunshine the entire dissolution of masses of ice many feet in thickness may occur in this manner. Of course the same kind of decay would destroy a hundred square miles of ice as readily as a hundred square inches.

Towards evening land was in sight, but the weather was too thick to see it plainly. Much snow was, however, visible on the higher ranges; and here and there along the coast, the pack could be discerned hemming it in. Our prospect of reaching Julianshaab tomorrow is, therefore, a poor one.

Aug. 17.—Owing, I suppose, to the powerful north-westerly current, we are still well to the northward of Cape Desolation. Last night the 'Bulldog,' under sail only, and with a light breeze blowing, came in for some heavy bumps, one large mass of ice seeming intent on trying conclusions with the starboard paddle. The damage done was only trifling, however. We are now running down in the direction of Cape Farewell under steam and sail, with the wind right aft. The ice forms a belt commencing about three or four miles from us, and stretches away to the land, which is distant about forty or forty-five miles. Whilst I write, the ship is receiving some heavy concussions.

Aug. 18.—This afternoon Cape Christian was sighted to the north-eastward, —the ice extending along the coast in a vast unbroken field of forty miles in diameter, and apparently increasing in quantity as the stream passes round Cape Farewell. The 'Bulldog' is now quite clear of the pack, and has made

the first sounding between Greenland and the mouth of Hamilton's Inlet, in north lat. 59° 22′ and west long. 45° 54′, the depth indicated being 1177 fathoms.

Aug. 23.—Inclusive of the soundings taken on the 18th inst., the depth has been ascertained fifteen times between Cape Farewell and our position at noon today. With the exception of the last sounding, taken at 9 A.M. in 280 fathoms, the depths have ranged between 1150 and 2032 fathoms, bottom having been brought up four times. In a distance of about seven or eight miles between the 280-fathom sounding and that immediately preceding it, there is a rapid decrease in depth from 1190 to 280 fathoms—being at the rate of about 700 feet per mile, or nearly identical with the dip which occurs off the west coast of Ireland in the mid-Atlantic line.

A sounding made this morning with Brooke's apparatus brought up only two grains of bottom,—a small stone, about half an inch in length by a third in width and thickness, having stuck in the valve and permitted the escape of whatever other material may have occupied the cavity of the cylinder.

Aug. 24.—On approaching Hamilton's Inlet, the coast to the north and south of it presented a singularly unattractive character. Instead of the bold rugged cliff-scenery of Greenland, nothing was to be seen but an unbroken succession of low rounded hills, with scarcely a trace of vegetation on their surfaces. This afternoon we passed the Esquimaux Islands, lying off the entrance to the inlet; and at 6 P.M. the 'Bulldog' anchored at Indian Harbour.

CHAPTER IV.

INDIAN HARBOUR.—COAST-FORMATION.—BLUFF-HEAD COVE.—RIGOLETTE.—THE NARROWS.—NORTH-WEST RIVER.—CLIMATE.—NUMBER OF SETTLERS.—MARL BED.—SPRINGS.—HAMILTON'S RIVER.—CULTIVATION AT NORTH-WEST RIVER.—BOULDERS.—EXTENT OF INLET.—NATURE OF ITS BED.—PROCEED TO SEA.—CAPE BRETON.—RETURN TO INDIAN HARBOUR.—SHOAL.—DEEP-SEA SOUNDINGS.—ICEBERGS.—ARRIVAL AT JULIANSHAAB.

INDIAN HARBOUR is situated in a sheltered channel between the mainland and one of the largest of the group of islands at the mouth of the inlet. An extensive cod-fishery is carried on here during the four summer months. At present it is drawing to a close, and only a few small vessels remain to complete their cargoes. Mr. Norman, a Newfoundland merchant, who comes to reside on the spot during the continuance of the fishery, informs me that the present has been an unusually stormy season, and that the quantity of cod taken has been far short of the average. On the other hand, the quantity of ice met with on the coast has been unusually small, the long prevalence of south-easterly gales having tended to drive the ice close in shore, higher up the coast of Labrador, so as to be beyond the influence of the descending arctic current. He says that although a vast number of bergs drift to the southward or ground in shoal water near the outer islands, they very rarely enter the inlet. Some of the fishermen, however, state that whilst the larger bergs cannot pass inside, moderate-sized ones are to be seen, at times in considerable numbers. But as the place appears to be altogether deserted during winter, in consequence of the severity of the climate, it is somewhat difficult to make out how far these assertions depend on actual observation, and how far on mere supposition or hearsay.

The entire coast seems to be composed of a grey disintegrated granite, in which there is a large preponderance of felspar, with vast basaltic dykes sometimes cutting the islands and hills longitudinally, sometimes constituting the entire mass. An island to the left of the entrance to our present anchorage presents a very remarkable dyke, of the kind referred to, just above and parallel

with high-water line. On another island, one of the loftiest in the neighbourhood, and distant from any other, the highest ridge is occupied by a series of immense boulders. How they attained this extraordinary position I am unable to surmise, our brief stay at Indian Harbour rendering it impossible for me to reach the island.

Although Hamilton's Inlet is in the same latitude as Sligo or Yorkshire, the climate and vegetation are purely sub-arctic, and in the neighbourhood of the sea, at all events, there is nothing approaching to cultivation.

Whilst dredging I found that, at a distance of a quarter of a mile from shore, the depth rarely exceeds 10 or 15 fathoms, and that the bottom is wholly formed of uncovered rock or boulders. The shore-line itself consists of large rounded masses of basalt and granite, which are destitute of organic growths of any kind above extreme low-water mark—owing, no doubt, to the long-continuing action of drift-ice and currents.

The method of catching the fish is somewhat singular, and shows that, with all the appliances of civilization, the white man has been unable to teach the Esquimaux how it may be improved. As carried on here, it is precisely similar to that practised by the kayakers in Greenland,—three hooks being attached to a slipper-shaped sinker, about 5 inches in length, which is "jigged" up and down as the boat drifts along. No bait whatever is used.

With a view to obtain some information regarding the depths of water and nature of bottom at this part of the inlet, I went alongside one or two of the boats. Although the men were catching fish as fast as they could let down their lines, they all corroborated the statement of Mr. Norman regarding the poorness of the fishery this year. Failing to elicit any facts bearing on the zoology of the bottom from the fishermen, it struck me it might be derived from the fish themselves. Accordingly I purchased forty, varying in weight from two to ten pounds, for the small sum of four shillings. On appealing to the stomachs of a few of these, I was equally unfortunate; for, with one exception, they were entirely empty. They appear to be hooked almost as often by the body as by the jaws, and in two out of the forty fish I had purchased there were distinct cicatrices showing where they had been hooked on a previous occasion. As all fish under a certain weight are thrown into the water again, those that survive their injuries would present similar marks.

Aug. 25.—Anchored in the evening at Bluff-Head Cove, about twenty miles up the inlet. The naked character of the shores is already replaced by a growth of dwarf spruce-fir, from one to three feet in height. The only resident in this lonely spot is a Dorsetshire man. He states that the inlet is completely frozen over in winter, and that his hunting-journeys are then made by sledge. His dogs are a breed between the true Esquimaux and the native Labrador dog. They are very handsome, and sociable to a degree that proves canine distrust to be engendered by man's presence rather than his absence. One of the dogs had lost a fore leg in an encounter with a bear, but seemed hardly to feel the loss of his limb. He was the leading dog of the team before the accident, and retains his post of honour still,—the absent member being replaced by a hide bag stuffed tightly with moss, and secured around the stump. Thus equipped, the poor animal performs his work, and frequently traverses from thirty to forty miles a day.

The soundings taken from Indian Harbour up to this point are composed of granitic sand, containing scarcely a trace of organic matter, either animal or vegetable. The almost entire absence of any of the ordinary sea-birds was very remarkable at the mouth of the inlet. The condition of the rocks indicated that none frequented them. As we ascend further up the inlet, a few Ravens, Sea-parrots, and Dovekies show themselves; but otherwise there is no living creature to be seen above water.

Aug. 27.—Early this morning the 'Bulldog' steamed up the inlet, taking bearings and soundings along her course. The hills on either side already become somewhat loftier and more wooded; but the spruce-firs seem only to thrive at a sufficient elevation above the shore-line to be beyond the influence of the salt-water spray, and are still of too stunted a growth to detract materially from the bare and unvaried character of the scenery.

Towards sunset several whales of small size were seen cruising about, but at too great a distance to enable us to make out the species. The pilot we took on board lower down the inlet states that no attempt has ever been made to capture these animals. About the same time immense flights of Puffins kept crossing over from the southern towards the northern shore, where, for some distance, the land appears to be flat and marshy; and it was very curious to watch the Dovekies rising up to the previously unruffled surface of the water as the ship approached,

scared to such a degree that for some moments they appeared unable to make up their minds from which of the two elements around them they might expect the greatest security. Owing to the calmness of the surface, it was possible to see a long way ahead; and although here and there a bird might bob up, there was nothing like the consentaneous uprising just referred to. The fact is worthy of record, because, although the powers of the Divers and Auks to remain under water for considerable periods are well known, it would almost appear that these little auks live as much below water as above it, and continue gregarious whilst diving.

This is the first bright moonlight night we have had since we put to sea. There is not a cloud in the sky; and the deep silence is broken only by the murmur of the tide against the sides of the ship. How different from a similar night-scene in the tropics, where a hundred strange noises, produced by night-roaming beasts, birds, and insects, would strike the ear, and impart to it a charm, the more intense the more unfrequented and wild the locality.

Aug. 28.—At 8 A.M. we arrived at Rigolette, a very picturesque little station belonging to the Hudson's Bay Company, occupied at present by a couple of their *employés*. It is situated in an extensive reach, bounded by granitic hills, clothed with spruce-fir and white birch. The salmon-fishery is carried on here on a large scale, but, as already mentioned, is just over for the season. It appears that two large decked boats which passed us yesterday afternoon were conveying the salmon, and also the furs collected, to Indian Harbour, where they are shipped for their destination by the Company's Agent.

The mosquitos are more numerous, more venomous, and larger than any I have ever seen elsewhere. No precaution short of tying the head up in a gauze bag suffices to protect it from their attacks; and my gauze nets were accordingly in great requisition. Wherever the skin is exposed for a moment, a dozen mosquitos immediately settle and draw large drops of blood. Their bloodthirstiness is only equalled by their stupidity; for whilst an Indian mosquito appears instinctively to know from the gesture of his victim when any attempt is about to be made to destroy him, and instantly retreats, these Labrador mosquitos go on sucking their fill, and stolidly await the blow which terminates their existence.

I endeavoured to make my way through the pine-forest to a freshwater lake

said to be distant a mile from Rigolette; but after walking for a mile and a half through a swampy sphagnum-covered clearing to the summit of a plateau commanding a view of the lake, I saw that at least a couple of miles still remained to be traversed, and accordingly returned in order to be back in time for the departure of the ship.

The heat today was quite oppressive. In some mountains visible to the westward, snow covers the summits. The Hudson's Bay officials inform me that the winter at this part of the inlet is by no means severe, although the temperature often falls as low as —30° Fahr.

Some miles above Rigolette the stream suddenly contracts, and, sweeping round a bluff island that rises up in the centre of its channel, rushes with great velocity through "The Narrows." At certain periods of the year the current at this portion of the inlet is said to attain a speed of from seven to eight miles an hour, and to prevent the formation of ice when the rest of the inlet is frozen over to the thickness of several feet. Not far from this point, a considerable branch is given off from the southern shore, which is said to extend in an easterly direction about fifty miles, but without forming any communication with the sea. This branch is called "Back River."

On emerging from "The Narrows," we entered a large expanse of water stretching away to the westward as far as the eye could reach, and apparently about twelve or fifteen miles in breadth. When we anchored for the night, there was still no land visible above the water-line to the westward*.

The higher we advance up this magnificent arm of the sea, the greater is the distance reported to be between its eastern and western boundaries. At Indian Harbour we were informed that the extreme length was between ninety and a hundred miles. Today, at Rigolette, it is stated to be nearly 120. I mention the circumstance because, although it is by no means to be wondered at, that persons moving about from settlement to settlement should only possess a general knowledge of the geography of the country, one would certainly expect to find the bearings of such an inlet as this correctly laid down in the most modern maps, and it seems almost incredible that, within a few hundred miles of our North American colonies and naval stations, an arm of the sea of sufficient

* This extensive tract of water is noted in some charts as "Melville Lake;" but none of the settlers along the inlet know it by that name. The Esquimaux name of Hamilton's Inlet is Ivuktok.

extent to shelter the largest fleet in the world, possessing very extensive salmon-, cod-, and capelin-fisheries, the shores of whose tributaries are said to abound in timber of large size which might be floated down in rafts and shipped in deep water, and whose mineral resources are probably neglected solely because they have been undeveloped, should have remained up to the present day so partially explored.

Aug. 29.—Arrived at North-west River, the head of Hamilton's Inlet, and the principal settlement of the Hudson's Bay Company in this part of Labrador. Towards the upper extremity of the inlet, the shores converge somewhat, and become gradually flatter and more closely wooded. At this point the channel receives the waters of "North-west" and "Hamilton's" Rivers. The former, or more northerly branch as its name implies, debouches into the inlet by a narrow channel only about eighty yards in width—the settlement being on the northern shore, and situated on a small tract of flat land from which the forest has been cleared. The opposite shore is low, and densely wooded to the water's edge, but none of the trees are above 30 or 35 feet in height.

Mr. Smith, the superintendent of the district, who has resided here for many years, speaks in high terms of the healthiness of the climate, notwithstanding the great alternations of temperature. He has known the thermometer in the month of July to stand at 110° in the shade, and to range at night up to 90°. But the last was an exceptional case. During the continuance of these extreme heats, the mosquitos, with which the inlet swarms to a degree unknown save in some parts of tropical America, vanished completely. Winter commences in November. The chief fall of snow occurs in January, the temperature then ranging from −5° to −50°. In 1856 it fell to −54°. Heavy gales occur in October. Last year two terrific hurricanes took place, on the 8th and 26th of October. The first continued for two days, and blew from the north-westward. The second lasted only for a few hours, but was by far the most severe. It blew from the eastward. If I am not much mistaken, it was on or about the latter date that the 'Royal Charter' was wrecked on our own shores. Rain falls very rarely except in August and September; but the fall is then very heavy and continuous. Mr. Smith states that the men complain more of the severe effects of the sun in spring, which blisters their faces and affects their eyes, than of the intense cold. They seldom wear furs, even in the depth of winter—their

clothing consisting of stout woollen undergarments with blanket coats and trousers, and mocassins made of deer-skin. When out in the winter, the hunter carries no tent, but only a couple of blankets, his gun, and his knife.

The skins brought to the settlement both by the Canadian and Indian hunters consist of the white and black bear, reindeer, a species of lynx, ermine, mink, sable, wolverine, and the white and black fox. The black fox-skin is by far the most valuable and the rarest. Only four were procured last year. Their value ranges from £10 to £15 on the spot, but in Europe they readily fetch from £30 to £40. It appears that they are not in such request for the European markets as for the Chinese. The skins are first purchased by merchants in England. From thence they are sent to the great annual fair at Leipsic, and ultimately find their way to China, where they are greatly sought after by the mandarins. The skin of the carabboo* is brought in from the interior by the Red Indians, but always in a tanned state.

All skins procured by the hunters are taken at a contract price by the Hudson's Bay Company's agent, the proceeds being divided equally amongst the men of the party to which the captor belongs. The advantages of this mode of reward are twofold, inasmuch as it stimulates every man to work energetically, and induces each party of men to coerce such as are inclined to be idle.

Salmon and salmon-trout are taken in great quantity throughout the entire length of Hamilton's Inlet and the rivers that flow into it. Mr. Smith states that the pike also occurs, and a species of shark about 4 feet in length, quite distinct from the dog-fish. I was unable to procure specimens, however. Capelins and cod-fish are only taken near the mouth of the inlet and along the coast.

The total number of settlers on the shores of Hamilton's Inlet, including those of mixed descent, is computed at 200. Although no new colonists come out, the settlers are gradually on the increase. On the other hand, the Esquimaux, who formerly were plentiful towards the lower portion of the inlet, are slowly dying out. Some years ago a great number were carried off in a very brief period by some virulent contagious disease. Their skeletons are still strewed over the surface of an island, not far from the one mentioned as occurring near "The Narrows," which retains the name of Esquimaux Island in consequence.

* This is believed to be a large variety of the Reindeer (*C. Tarandus*); but, from the description Mr. Smith gave of it, it would almost appear that a distinct species was referred to.

We found a party of American Indians, belonging to the Cree tribe, encamped on the shore a little way from the settlement. The main body had left only a day or two before. They had come down from the interior to barter skins for articles of English manufacture and food, such as blankets, cloth, hardware, and biscuit. The value of all these is regulated by a tariff with which they have become familiar; for no money transactions are carried on. In like manner there is a fixed value imposed on all kinds of skins.

It is a curious fact that the Indians will, on no account, bring in the entire body of the carabboo deer, or indeed any portion but the skin. There is a superstition current amongst them, that whoever brings one of these to the white man will meet with dire misfortune, and that his hunting-grounds will be destroyed. Mr. Smith informed me that although large bribes have been offered for specimens, they have proved unavailing, the Indians declining to bring in even the head or horns. He added that he had no doubt that, were he to order an Indian hunter to bring in a carabboo, the order would be obeyed; but any subsequent mishap or loss would at once be referred to his agency, and the trade might thereby be very seriously injured. The Indians subsist in a great measure on the flesh of the carabboo; but they leave the bones and other remains on the spot where they cut it up, and invariably tan the skin before bringing it to the settlement.

Hearing that a bed of marl and shells occurs some way up North-west River, I proceeded to the spot in an Indian birch-bark canoe. About 200 yards above the settlement the North-west River spreads out into a large nearly circular sheet of water, about three miles in diameter. A narrow channel, similar to the one opposite the settlement, but of greater length and fringed with the densest pine-forest, succeeds this, and opens out into another large expanse of water, called "Grand Lake." This is about three miles in width, and is said to extend westwards for forty miles, where it terminates in a small river amongst the mountains. At each of the narrows there are rapids, but not of sufficient velocity to prevent a boat being rowed up close along the shores. At the spot indicated, I found a disintegrated calcareous marl, wholly made up of minute friable portions of a Mytilus-shell. The underlying strata were not visible, as the shore was densely wooded down to the water's edge, and the underwood had only been cleared away where the marl had been dug. The frag-

ments of shell have the fibrous aspect of asbestos, but crumble with the slightest touch. The deposit must have been derived from salt water at a period when this portion of the inlet was considerably lower than it is at present, and thus subject to the constant influx of salt water. There are no marine mollusca found now within many miles of the head of the inlet. In the water immediately adjoining the marl-bed, and down as far as the settlement, Limnæas occurred in great abundance, adherent to stones. The water above the settlement is perfectly fresh, as might be anticipated from the strength of the current. At our anchorage the hydrometer indicated nearly pure fresh water. And yet the tide influences the inlet at this distance from the sea, namely, 120 miles. In winter, I am informed, the amount of saline admixture, in the vicinity of the anchorage, becomes very perceptible. On inquiring whether freshwater springs occur along the shores, my boatmen mentioned that a remarkable spring was to be met with about half a mile higher up. On paddling to it, I was much astonished to see one large and several smaller geyser-like orifices at the sandy bottom of the river, where the depth was about a foot and a half. Their orifices were well defined, and could readily be examined, from the perfect clearness of the water. The orifice of the largest was 6 inches in diameter, quite circular, and surrounded by a cone-shaped crater of sand. Through this the water spouted with sufficient force to cause the jet to rise to a considerable elevation above the surface of the stream. The temperature was at least ten degrees below that of the river-water, and therefore leads to the inference that these springs take their origin in some of the more distant and elevated mountain-ranges. There are seven smaller springs, with apertures varying in diameter from 1 to 3 inches. The whole are distributed over an area of about 8 yards square,—the bottom of the river in their vicinity, and even the gravel-covered shore, which, to all appearance is perfectly firm, affording a most treacherous and somewhat dangerous footing.

It is currently believed here that some stupendous waterfalls occur at a distance of about 200 miles up Hamilton's River. The Indian hunters are well aware of the existence of these falls, but speak of them with such a degree of superstitious awe as to account for their admission of never having approached within sight of them. They concur in the statement that at twenty miles distance the roar of the cataract is terrific, and that, on coming within three miles, the vibration of the ground is so great as to give the impression of sub-

terranean action immediately underground. It appears, however, that some years ago Mr. Maclean, a gentleman in the service of the Hudson's Bay Company, whilst endeavouring to reach the east coast of Labrador from the westward, inspected these falls. In an account published by him of his journey*, Mr. Maclean states that, at a distance of six miles above the cataract, the stream contracts in width from 600 to about 100 yards, and, after rushing along in a continuous foaming rapid, finally contracts to a breadth of about 50 yards, when it precipitates itself over the rock which forms the fall. It now continues its course, pent up in a precipitous zigzag gorge, for thirty miles—the walls of rock sometimes rising to a height of 300 feet on either side, and concealing the torrent from view till the chasm is reached. The formation is said to be syenitic.

At North-west River, oats, barley, potatoes, cabbages, turnips, and rhubarb have become articles of regular produce, but as yet only in limited quantity—the scanty nature of the surface-soil, which is characteristic of the shores of this inlet, rendering cultivation of all kinds difficult, notwithstanding the high temperature during the summer months, and the great facilities of irrigation. Hay-making is now going on, the thermometer standing, in the shade, this afternoon, at 84° Fahr.

Aug. 30.—Leaving North-west River at an early hour this morning, the 'Bulldog' commenced her return voyage down the inlet, and at noon anchored off the bluff headland known as "Long Point," in order to survey.

The hills in the vicinity of this headland are entirely composed of a grey finely striated labradorite, traversed by narrow dykes of dense black basalt. At North-west River, wherever the rock formation cropped out, the same kind of labradorite was to be seen. The shore is here covered with a succession of large rounded boulders of felspathic, and also hypogene rocks not to be met with in the immediate neighbourhood. Some of these were as much as 3 feet in diameter, and indicate that the drift-ice, by which it is probable they were transported to their present position, must have been of very considerable thickness. At North-west River I learned that in ordinary seasons the ice on the inlet attains a thickness of three feet. At Chator Island, on which I landed on the 27th inst., I saw some boulders of quartzose rock, at least 5 feet in diameter.

* 'Notes of a Twenty-five years' Service on the Hudson's Bay Territory.' By J. Maclean. London, 1849.

Wherever I landed along the shores of the mainland, there was a thick-matted layer of sphagnum and lichen growth. At "Long Point" this was almost completely obscured here and there, where the forest did not extend, by a network of red and black whortleberry, wild yellow raspberry, and, on the more rocky surfaces, common juniper and crowberry. The fruit of the first of these was so plentiful that it could be shaken off in handfuls. Both bears and ptarmigan, which abound in the neighbourhood, feed on it almost exclusively. Lower down the inlet the wild fetid currant was met with.

The 'Bulldog' proceeded on her course at 3 P.M., and, after encountering a very powerful current whilst rounding a headland abreast of Esquimaux Island, anchored for the night in Esquimaux Harbour. This current was an ascending one, due to the flood tide.

The length of Hamilton's Inlet, from Indian Harbour to North-west River, is 118 miles. At its mouth the width is nearly fifteen miles, the deepest water at this part being about the central portion of the five miles intervening between George Island and the northern shore. The bottom, as brought up by the sounding-machine along the navigable channel, consists of detritus of granitic, basaltic, and felspathic rock, with an extremely small sprinkling, as far up as "Bluff Head Cove," of the lower animal and vegetable forms. From that point up to North-west River, it consists of a coarse felspathic and quartzose sand, without any organic structures whatever. Near the sea the bottom is coarsely muddy; but the finer particles gradually disappear, and at the head of the inlet the quantity of mud is inappreciable, the bottom consisting entirely of clear sand. Wherever I dredged near the anchorages in shallow water fringing the shore, I found *Algæ*, *Confervæ*, and the more minute forms of animal and vegetable life abundantly represented, and large quantities of fine mud. The very marked paucity, and in some places total absence, of minute organic forms, fine mud, or débris of the larger organisms, clearly points to the current being of sufficient velocity to wash out the central channel, as it were, and convey the particles thus acquired far out to sea.

Sept. 16.—On the 31st ult. the 'Bulldog,' having completed the survey of Hamilton's Inlet, proceeded to sea and sounded, in a north-easterly direction, as high as lat. 56° 2′ N., long. 54° 3′ W. The course was now altered, and, steering to the southward, she passed through the Straits of Belle Isle on the 3rd inst., and

arrived on the morning of the 6th at Sydney Harbour, Cape Breton. Having completed coaling, the ship started on her return voyage on the 12th inst., and, taking an inner line of soundings, commencing in lat. 52° 44′ N. parallel with the south-eastern coast of Labrador, this evening once more came to anchor at Indian Harbour.

Leaving Indian Harbour on the 17th September, soundings were taken from the entrance of the inlet, in a northerly direction, along the 57th degree of latitude, as far as 55° 33′ N. At this point a sudden increase of depth occurs, from 148 to 950 fathoms in a distance of seven miles; being at the rate of 687 feet per mile, or somewhat less than the Valencia dip. These several lines of soundings prove that a shoal extends north and south of Hamilton's Inlet for three degrees of latitude, and for a distance of at least a hundred miles in an easterly direction from its entrance. Hence this shoal would appear to be a continuation of the one referred to by Sir J. C. Ross* as occurring off Labrador, in lat. 57° 30′ N., and stated by that distinguished arctic navigator to stretch parallel with the coast for a considerable distance both north and south of the latitude of Okak, a Moravian settlement to the southward of Cape Mugford. Sir James Ross mentions that the depth of water in that neighbourhood is 60 fathoms, and that the shoal is marked by the line of icebergs which were grounded on it on both the occasions on which he crossed it. In approaching the coast and in our passage outwards from it, icebergs were seen, but not in any great numbers. To the southward of Labrador, the soundings, both as regards depth of water and nature of bottom, would seem to indicate that this shoal is continuous with the great bank of Newfoundland; and whilst the material that forms it northward of the 53rd degree of latitude is derived from the vast outpourings of Hamilton's Inlet and the rivers that flow into its western extremity, the more southerly portion, namely, that which extends from the 53rd degree of latitude to the most southern limit of the Newfoundland shoal, is derived partly from the same source and partly from the outpourings of the Gulf of St. Lawrence.

But although, as I have already stated, there is every reason to believe the shoal referred to by Sir James Ross, as stretching north and south of latitude 57° 30′ N., is continuous with the shoal determined by the 'Bulldog' soundings, inasmuch as there is nothing known of the coast-formation or the course of

* 'Parliamentary Report to inquire into the Construction of Telegraph-Cables,' p. 188, 1861.

the arctic drift which could suggest the probability of an intermediate deep channel, it must be borne in mind that the depth between lat. 55° 30′ N. and 57° 10′ N. (that is, allowing the southward extension from the latitude of Okak as determined by Sir J. Ross's evidence) remains to be ascertained, and that a deep channel *may* exist in this interval. But as the two deep soundings recorded by the 'Bulldog' occur near the 57th degree of latitude, and the coast-line falls back to the north-westward, in the direction of Okak, it is probable that the shoal-water margin ranges in a similar direction, and, accordingly, that the two soundings in 950 and 1190 fathoms were to the eastward of it.

Sept. 29.—Julianshaab. A continuance of bad weather and several heavy gales have protracted to thirteen days a voyage which could easily have been performed in two; and hence the 'Bulldog' only succeeded in reaching Julianshaab this evening. Since we deviated, on the 17th inst., from the shoal in the 57th degree of west longitude, three soundings have been taken—the first in 1938 fathoms, the second in 2000 fathoms, and the third in 1912 fathoms, bottom being brought up twice.

Yesterday, during a severe gale, a swallow (*Hirundo rufus*) was blown on board and caught. From the direction of the wind, it is probable that the bird must have come from the Labrador coast, the nearest point of which is distant 540 miles. On being brought down to the ward-room, it seemed to relish the warmth and rest, and did not hesitate to perch on the finger held out to it. Under the influence of extreme cold, fatigue, and hunger, all instinctive fear seemed to be eclipsed; and on being left alone after a while, the poor little animal ensconced itself under the globe of a lighted moderator-lamp. Putting its head beneath its wing, it soon fell asleep, dreaming perhaps of green fields and summer skies it was never more destined to enjoy on this side the Styx.

Today we passed through a vast quantity of drift and berg-ice, and, at a distance of about thirty miles from the coast, fell in with a much larger number of bergs than we had previously seen congregated together. At one time I counted upwards of eighty, many of which were of very large dimensions. Owing to the sea being so thickly covered, the water was perfectly calm, and the 'Bulldog' threaded her way through the icy labyrinth with perfect ease and safety. About sunset we made the long rocky spit which bounds the southern angle of the entrance to Julianshaab Fiord, and in an hour more reached the anchorage.

CHAPTER V.

JULIANSHAAB.—SEVERITY OF SEASON.—OLD SCANDINAVIAN RUINS.—SCENERY OF FIORD.—DEPARTURE FROM JULIANSHAAB.—ICE.—GALES.—BESET.—ESCAPE FROM PACK.—TERRIFIC HURRICANE.—UGLY BERG.—BOULDER AND DETRITUS-LADEN BERGS.—CAUSES OF THEIR RARITY.—THEIR FREQUENCY IN HIGH ARCTIC LATITUDES.—INERTIA OF MASSES OF PACK-ICE.—TALLERT BANK A MODERN DRIFT-BED.—SUBGLACIAL VALLEYS.—THEIR MODE OF FORMATION.—CAVERN-REMAINS.—EFFECTS OF TILTING OF BERGS.—SOUNDINGS.—SUBMERGED LAND.—A MESSAGE FROM THE DEEP SEA-BED.—"THE GRENADIER'S CAP."—REKIAVIK.—CLOSE OF THE CRUISE.

Oct. 1.—Julianshaab is situated in lat. 60° 43′ north, long. 46° 1′ west, at the head of a small sheltered bay which branches off from the Igaliko, or, as it is sometimes called, the Julianshaab Fiord. It is one of the most important settlements on the south coast, and constitutes the dépôt whence the oil and furs collected in the adjacent district are annually shipped for Copenhagen.

Although but a month and a half have elapsed since the expedition left Goodhaab for Labrador, the change in the temperature of the air and the general aspect of the country is very marked. Already snow falls daily, and the surface of the fiords is covered every morning with a thin layer of ice. The Danish residents fully corroborate the statements made at Goodhaab regarding the almost unprecedented severity of the season, and contrast it with the equally unprecedented mildness of the last. They inform me that, although during average seasons the belt of drift-ice effectually bars the ingress of vessels approaching from the sea until the middle of July or beginning of August, there is generally sufficient clear water close in shore to admit of communication by boat between the various settlements along the coast. This year such communication has been almost wholly suspended, and, up to the present date, the Danish vessel which usually arrives with the annual supplies for the colony about the period mentioned is still due.

A peculiar interest attaches to this portion of Greenland from the presence of some old Scandinavian ruins which are supposed to be those of the "East Bygd." Those at the upper extremity of the Igaliko Fiord are the most extensive, and,

according to a current tradition, mark the spot where the last remnant of the adventurous Norsemen who colonized the country between the 9th and 14th centuries were treacherously massacred by the Skrælings.

Oct. 2.—Today I accompanied Sir Leopold M'Clintock in a boat-expedition to examine the ruins, about fourteen miles distant, at the head of the fiord. The weather could hardly have been more unpropitious, inasmuch as snow fell without intermission, and both in going and returning we had to make way against strong head winds. This circumstance, no doubt, imparted a more sombre character to the fiord than it would otherwise have exhibited; yet I doubt whether, under the most favourable conditions as to season and weather, a scene in which there is such an absence of variety, and such vast proportions are associated with desolation so palpable, could be viewed without engendering a sense of profound gloom. This remark applies, however, only to the portions of the fiord between the settlement and its eastern terminus. In the vicinity of the ruins the scenery appeared beautiful, notwithstanding the disadvantages under which it was seen. There the channel, instead of being overshadowed on one side or the other by stupendous precipices, inaccessible save to the sea-gull, spreads out into a broad lake-like expanse, with a gently sloping shore stretching back for nearly half a mile from the water's edge, and then terminating at the base of the mountain-range which protects it to the north-eastward. On this slope the ruins alluded to are situated *.

Oct. 6.—At daybreak on the morning of the 3rd the 'Bulldog' left Julianshaab, and slowly made her way through a dense body of ice which had drifted up with the westerly wind since the previous afternoon and nearly closed the channel. On getting out to sea the quantity of ice, both berg and pack, was found to be much greater than it had been at any previous period since we reached the coast; and in forcing a passage into clear water the ship received a number of very severe collisions. In one of these, which made every timber vibrate from stem to stern, a large piece of the cutwater, about 2 feet square, was carried away. The paddle-floats, as might be expected, also met with

* For a detailed account of these ruins, and information regarding the East and West Bygds, the reader is referred to Captain Graah's 'Narrative of an Expedition to the East Coast of Greenland,' and the 'Historical Monuments of Greenland,' published by the Royal Society of Northern Antiquaries.

serious injuries. At 6 P.M. the ship emerged from the edge of the pack; but shortly afterwards she was again suddenly beset, and it became necessary to lie to for the night. During the latter portion of the night it blew hard, and snow began to fall in great quantity. Yesterday morning the decks and rigging were covered with a deep layer of snow and ice, which rapidly accumulated although removed at short intervals. The masses of pack-ice were of immense size, some of them rising out of the water nearly on a level with the bulwarks, and measuring from 50 to 60 yards in diameter. During the greater part of the morning snow fell so thickly as to obscure objects at twenty yards distance, and all attempts at clearing the ice were fruitless till about noon, when the ship once more found herself in open water.

Oct. 10.—During the whole of the 7th and 8th we experienced heavy gales off Cape Farewell. On the afternoon of the last-named date, the 'Bulldog' approached within five or six miles of the coast, in the vicinity of Prince Christian Sound, without meeting with any ice-pack. The mountain-ranges at this point seem to extend down to the sea, forming a series of lofty and precipitous escarpments, with intervening fiords and outlying islands. A sounding, taken at the above distance from the coast, showed the depth to be 94 fathoms. A second sounding, taken in the evening, at thirty miles distance, gave 205 fathoms. As night closed in, the gale steadily increased in violence, and, the wind having veered round from north to north-east, whilst our position was still far too close to the southern portion of Greenland to be safe from the dangers of a lee shore, things certainly looked far from promising. From an early hour yesterday morning it blew a terrific hurricane. Not a man in the gallant ship's crew, from the commander downwards, had ever encountered one more severe. To describe it is impossible; for sea and sky were alike obscured by the sheet of seething foam, within which they met in a deadly struggle for mastery. Every moment gigantic waves swept over the ship, as if bent on engulfing her. Everything hoisted in the shape of canvas was blown to tatters. Even the massive engines of the 'Bulldog' were utterly powerless against such a turmoil. Boats, bulwarks, paddle-boxes, bowsprit, and jib-boom, sponson-flooring—the latter formed of 9-inch beams—and tiller-head were more or less shattered to pieces or altogether carried away. The ship laboured terribly, her immense timbers and bulkheads working as if they were going to open outright. Only one sound was to be

heard; and that was the rush of waters and the mad howl of the tempest. It was indeed a sublime sight, and well worth witnessing; but, as there is little fear of such a scene fading from the memory, I candidly confess, to see it once in a lifetime is sufficient for all purposes.

Towards evening the rough edge appeared to have been taken off the gale; but nevertheless it continued during the night to blow furiously. This morning the glass has risen a trifle, and the storm moderated, but there is still plenty of room for improvement.

Oct. 11.—Another hand at the bellows, and from an opposite quarter. During the night the gale continued much as before. The rain which fell had taken the sea down somewhat. But after 11 P.M. the glass again fell, and it was evident the partial lull was only intended as a prelude to a renewed outburst. By 8 A.M. today it commenced to blow fiercely from the westward; and although the recent north-easterly hurricane had still left a tremendous swell, this was rapidly overcome, and succeeded by another from the opposite point of the compass.

About an hour ago the engines had to be disconnected, in order, I believe, to effect some repair; and no sooner had this operation been performed than we found ourselves within a short distance of a large iceberg. The ship's head refused to "pay off;" that is, the effect of the wind on her broadside and immense paddle-boxes was so great in proportion to the power of such sail as it was possible to set, that it occupied nearly half an hour to get her head round, and thus gain the leeward side of the only really ugly berg I have seen since we came to Greenland.

At a rough estimate, I should say the berg must have been about 80 feet in height above the main sea-level, and 100 feet in length. Against this mass of ice the mightiest waves hurled headlong without producing the faintest trace of oscillation; whilst in an instant afterwards they might be seen borne away to leeward, 100 feet at least higher than its summit, as scattered mists annihilated by their own wild vehemence.

It is remarkable that, amongst the numerous icebergs met with in deep water since our first arrival on the Greenland coast, I have only observed seventeen that have presented distinct traces of gravel, stones, or detritus from the bottom. For a time I was perplexed how to account for this, inasmuch as in higher lati-

tudes examples of the kind are known to be frequent. But the comparatively small number of bergs which afforded evidence of their having been reversed or tilted over on their sides suggests an explanation, namely, that so long as icebergs are afloat, the great preponderance in bulk of the submerged portion in the generality of cases renders the effects of wasting above water, or the force exercised by winds and waves even when at a maximum, powerless in disturbing their centres of gravity. Although soundings taken both on the east and west coasts of Greenland clearly indicate that, for distances varying from five to thirty miles from the shore-line, the depth is sufficiently moderate to admit of the grounding of the larger bergs, there cannot be a doubt that the percentage of bergs thus arrested in their transit is so trifling in comparison with those that drift up to the head of Baffin's Bay as to render the cases exceptional. Again, those cases are still more exceptional in which, when large bergs take the ground, they are subjected to impact of bergs equalling or nearly equalling them in dimensions. In the first place, the number, although very great in this part of the ocean, is insignificant in relation to the area over which they are distributed; and in the second, the very nature of the current by which they are borne onwards renders such an occurrence extremely rare, since disparity in the rates of progression of different bergs can only result from disparity in their masses and consequent extent of immersion. In other words, the smaller the berg, the more rapidly would it drift; and hence in the event of a berg overtaking another, and coming into collision with it, the one most likely to be overturned or crushed would be the smaller, and not the larger of the two.

In the event of a continuous field of pack-ice being drifted against stranded bergs, the accumulative force would suffice to overturn or even crush the largest met with in these latitudes. Such an event, in all probability, occurred in the case of the grounded berg alluded to by me as having been seen on the evening of the 31st of July; and I therefore doubly regret that an untoward accident of weather prevented us from witnessing a collision the effects of which must have been so stupendous. Although I was unable to obtain information with regard to the characters of the bergs met with beyond the immediate coast-line from our Danish friends at Goodhaab and Julianshaab, the opinion I have expressed, regarding the extreme rarity of examples in which drift or detritus is observable, is fully borne out by Mr. Tayler, an English gentleman who has resided in

South Greenland for seven years, and has had many opportunities of arriving at a correct knowledge on the subject. He has informed me that not one berg in a thousand of those which drift along the coast presents the appearances in question. To this statement I would append the inference I draw from it, namely, that not one berg in a thousand of those met with below the 64th degree of latitude on the western side of Greenland comes under the influence of those forces which are necessary to alter its centre of gravity to any material extent. I am far from asserting that, where boulders or detritus occur, the surface occupied by them necessarily represents the original base of the mass before it was projected from its parent glacier; but, judging from the appearance of the greater number of large bergs, I think it may be accepted as true that the direction of their upper and under surfaces has not been altered since they constituted part and parcel of the glacier, and that the presence of foreign matters, such as stones and gravel, in most cases is due to their having grounded after being detached, and floating away again only when reduced sufficiently in bulk, by the temperature present, both above and below water. It is also well known that bergs may receive deposits or even boulders whilst afloat by coming into contact with overhanging rock-surfaces; but these examples are obviously too exceptional and rare to affect the present question.

I have already noticed how constantly the submerged portion of bergs spreads in a lateral direction, thereby augmenting the firmness of their bases; and coupling all these facts together, I think it becomes evident we must look for the force capable of coping with masses of matter of such immense volume in that crowding together of bergs which only takes place in higher latitudes, precisely in the same manner that the masses of ordinary pack-ice are crushed and turned over in every possible way by masses of equal proportions with themselves when closely pressed together in drifting fields. In the case of a berg drifting along in shoal water, this extraordinary force is not necessary to produce the result, inasmuch as the momentum of the mass itself, or the leverage exercised by winds or currents, would suffice to tilt it over on its becoming stranded. There is ample proof of this process taking place, inasmuch as in shallow water bergs may frequently be seen laden with gravel or detritus, and exhibiting distinct evidence of having been reversed or tilted over. On the other hand, nothing can demonstrate more conclusively the insignificance of the

forces in operation above water as compared with these ice-masses, so long as they continue afloat, than the majestic immobility of the berg seen on the 11th of October during the continuance of one of the severest gales we have encountered in these waters.

In illustration of the enormous force requisite to move a mass of pack-ice even of moderate dimensions, I would mention that on one occasion, in the vicinity of Frederickshaab, the port paddle came into collision with a piece the superficial diameter of which was about 70 or 80 feet, whilst its average height above water was about $3\frac{1}{2}$ feet, and that, instead of the ship causing the mass of ice to oscillate, the paddle actually mounted on the ice-surface, and caused the ship to heel over until it again became disengaged.

The solitary instance in which I observed evidence of large masses of rock or boulder having been impacted in a berg also occurred during one of our attempts to approach Frederickshaab. This berg was probably about 120 feet in height, and from 300 to 400 feet in length. About 20 feet above the water-line two large cavern-like apertures existed, the inner surfaces of which retained the mud and detritus left behind on the disengagement of the boulders that originally occupied them. Several small stones still remained imbedded; and around them were to be seen smaller cavities, precisely resembling the two first described. Indeed, I should never have suspected that boulders had lodged in the larger cavities, but for the similarity in character between them and the smaller empty ones. I infer that the larger could not have materially increased in diameter by the process of thawing or wave-washing, solely from the presence of the detritus, which in that case would have disappeared.

At Goodhaab I repeatedly came across small bergs in the fiords, laden with mud and detritus, and sometimes carrying imbedded stones of moderate size. One of these I was induced to examine more closely than perhaps I should otherwise have done, having "stalked" what I conceived to be a large black bird perched halfway up on its face, and on close approach discovered it to be one of these impacted boulders, about a foot in diameter.

The large shoal called the "Tallert Bank," to which I have drawn attention in a former page as being composed of detritus brought down from the interior of the land by a river debouching under the great ice-blink, affords an example of the conditions under which the smaller class of bergs receive detritus. That

bank, which is a drift-bed now in process of formation, would in all probability present every condition, both as regards mineralogical composition and the character of its organic remains, that occurs in the ancient drift-beds of the Post-pliocene period.

Whilst at Julianshaab, I was informed by Mr. Hoyer, the Assistant Superintendent of the colony, who has explored the so-called continental ice of South Greenland for a considerable distance into the interior, that crevasses are occasionally to be met with, of no great width, but whose depth is so great that a fragment of ice dropped into them can be heard to reach the bottom after the lapse of a very considerable interval; whilst in some places the sound of running water and cascades at great depths can be distinctly recognized. The Esquimaux assert that, during the most severe period of the winter, the reindeer flock together in herds *under* the hollow portions of the continental ice, and that they actually find food, such as lichens, in these vast ice-vaulted wildernesses when none is attainable elsewhere. Without pretending to deal with the proofs that are required before such a statement can be accepted as a fact, I must say I am unable to adduce any weighty reasons why it should not be so; whilst, on the other hand, sundry plausible arguments could be brought forward which tend to show not only that such sub-glacial tracts *may*, but in all probability *do* exist.

In the event of a glacier forming in a valley traversed by a shallow stream during the warmer months, the first effect of the influx of a much augmented volume of water at a temperature considerably above freezing-point would be to produce a series of arched passages, which would subsequently increase in vertical dimensions in consequence of the obstructed outflow keeping them filled, and thus subject to a protracted thawing action. On the recurrence of winter, the onward progress of the glacier would more or less completely block up the outlet, without obliterating the previously formed subglacial channel. On the return of summer, the now enlarged channel would at once be filled up with water of sufficiently high temperature to extend its boundary walls still further, —these two operations being repeated indefinitely through a lapse of centuries, and eventually resulting in the subglacial tract referred to. Under the same circumstances the waters flowing down into this tract would convey and deposit the spores of lichens, and possibly the seeds of phanerogamic plants, which, on

the recession of the water at the close of the warm season, might germinate and gradually spread themselves.

Supposing the above theory to be admissible, it would throw some light on the cave deposits and remains. In the event of herds of animals, such as reindeer, congregating together in these subglacial valleys, should their egress be prevented by the collapse of portions of the glacier, or the sudden irruption of floods, they would be swept away with the current, and their remains imbedded in the drift-bed, such as escaped into the more elevated crevices and caves (which are nowhere more abundant than in the rock formation of South Greenland) dying there, and being after a time covered over with detritus.

Where the Ruminants had penetrated, the indigenous Carnivora would follow, and thus the remains of both orders might become mixed up in the same localities; whilst the drift-beds formed at the mouths of the valleys would become the receptacle for the remains of the entire local fauna of the period, terrestrial as well as marine.

Lastly, this view would tend to show that the deep furrows which occur on the upper surface of the ancient drift-beds and are generally found filled up with a muddy deposit, had been formed by the transit of ice-bergs, the traces of previously formed furrows having become obliterated by the gradual subsidence of gravel in lieu of the lighter mud originally occupying them.

Before closing my observations on icebergs, I would allude to an occurrence which, although at first sight paradoxical, admits of a very simple explanation. It must have fallen under notice again and again; but as it bears materially on the safety of submerged telegraphic cables, and has not been taken into consideration in connexion with that subject, I may be permitted to illustrate it. I allude to the case of bergs which require deeper water for their flotation, after being diminished in bulk by the breaking away of a portion, than they did previously, and the consequent possibility of their grounding and inflicting injury on a cable after having floated innocuously over the spur or shoal which is supposed to divert all bergs of sufficient volume to ground within the barrier. The subjoined woodcut represents an appearance I have repeatedly met with in bergs, both out at sea and in the fiords. The height of the example under notice was about 40 feet, its length being about 100 feet.

The shaded portion of fig. 1 shows the berg as seen above the water-level

A A,—one half of the original line of flotation *a a* being visible, the other half being submerged. The dotted outline gives an ideal view of the portion below water, the submerged half of the original line of flotation being shown, and the base of the berg *e f*. Fig. 2 gives an ideal view of the same as it appeared before the separation of the mass *d*, B B being the bed of the fiord.

Fig. 1.

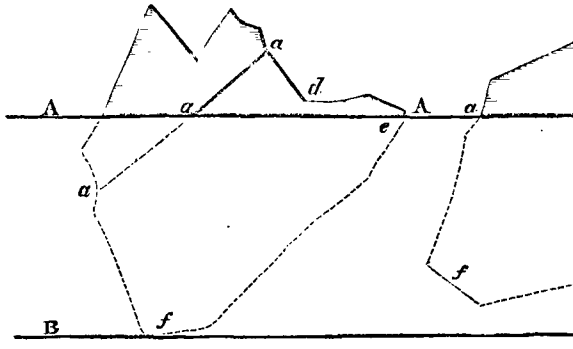
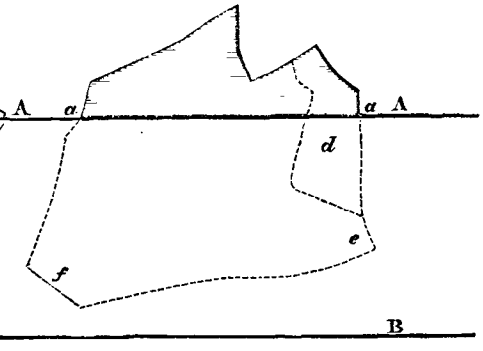


Fig. 2.



There are evidently but two modes in which the horizontal line, *a a*, could have been tilted up as seen in fig. 1; that is, either by the addition of a mass in the direction of *f*, or by the separation of a mass in the direction of *e*. Either of these causes might produce the result. In the case of floating pieces of ice, however, the latter would be the more likely occurrence; and in the example under notice, it was quite manifest, from the appearance of the surface, that a large mass had recently been detached at *d*. Such a mass, although materially adding to the cubical contents of the berg, would have the effect of distributing the weight equally round the centre of gravity, and of sustaining the portion at *f* at a higher level by acting as a counterpoise, as shown in fig. 2. On the other hand, it is evident that the separation of such a mass as *d* would at once throw the centre of gravity further towards *f*, and thus cause it to assume a deeper level, as in fig. 1.

Although these diagrams represent an imaginary case, in so far as the portion below water is concerned, there cannot be a doubt of the fact which they are intended to demonstrate, namely, that it is an error to assume that because a mass of ice drifts along in a given depth of water without touching the bottom, it may not, by such a process as has just been described, tilt over and immediately ground. It is obvious, therefore, that the mere circumstance of a fiord being

furnished with rocky spurs projecting into the sea at its entrance, or having a bar across its mouth upon which the depth of water is less than in the channel of the fiord itself, constitutes no protection to a telegraphic cable submerged along it, and that there is but one set of conditions which can be accepted as affording unquestionable security, namely, that furnished by a channel sufficiently deep to prevent the possibility of the largest bergs grounding under any circumstances whatever, and extending from deep water out at sea to the extreme verge of the terminus at which it is intended to land the cable. Instead of the grounding of bergs at a given distance from a coast-line affording this security, it proves the liability to the entrance of these masses wheresoever they can find a channel and atmospheric and tidal influences come into operation. Some channels are no doubt less liable than others to the entry of bergs, either on account of their direction with regard to prevailing winds and currents or their tortuousness; but the first obstacle must necessarily be regarded as uncertain in its results, whilst the rock or shore formation which invariably accompanies the second renders great fluctuations in the depths inevitable. In the case of channels through which the discharge of water from the land is so great as to oppose the entry of bergs, it is almost needless to say the action of boulders and abrading surfaces would only alter the kind of danger, without diminishing it.

On reference to the Map, it will be seen that, up to the period of our departure from Julianshaab, one line of soundings, divided into three sections with reference to the countries visited, has been completed, namely, from the Faröe Islands to Iceland, from Iceland to the east coast of Greenland, and from the south-western portion of Greenland to Hamilton's Inlet in Labrador, the last section having been re-traversed on the return voyage of the 'Bulldog.' Since our last approach to Greenland in the vicinity of Christian Sound, a fresh line has been entered on, stretching direct from Cape Farewell to Rockall. Since the 8th instant, four soundings have been taken, two of which present most interesting results, although in one of these only was material brought up from the bottom in sufficient quantity to indicate more than the fact of its having been reached by the sounding-machine.

In the first of these four soundings, which was taken in lat. 59° 48′ N., long. 37° W., the depth (1620 fathoms) is remarkable as showing a decrease of 336 fathoms in comparison with that of a sounding taken during the outward

voyage from Iceland to the east coast of Greenland, in nearly the same meridian, but in lat. 61° 57′ N. The second sounding, in lat. 59° 47′ N., long. 32° 43′ W., indicated a depth of 1168 fathoms, or a still greater decrease as compared with the depth of a sounding taken three degrees to the northward, the difference amounting to 404 fathoms. The third sounding, taken in lat. 59° 39′ N., long. 29° 38′ W., gave a depth of 748 fathoms only, or, as compared with a point four degrees to the northward and nearly in the same meridian of longitude, a decrease of 338 fathoms,—these three soundings jointly indicating that along a tract extending from the 29th to the 37th degree of west longitude, in the two lines separated by a mean interval of about three degrees of latitude, the more southerly line shows a mean decrease in depth of 360 fathoms.

"The discovery of a plateau partially raised above the surrounding level of the sea-bed, when considered by itself, might naturally be regarded as an isolated fact of little import, and not necessarily dependent on any extraordinary convulsions of the earth's surface; but it assumes a very different aspect when viewed in connexion with historic records, which declare that dry land, or, at all events, land so partially submerged as to be a source of danger to navigators, actually existed several centuries ago in the locality referred to; and hence it would almost countenance the supposition that, at a still more remote period, this tract may have constituted one of the successive stepping-stones by which North-western Europe and the North American continent were united.

Although it is impossible to say how far the volcanic action, of which Iceland now constitutes the centre, may have extended in a southerly direction during past ages, when we take into consideration the distances to which such agencies have actually been known to extend, the occurrence within little more than half a century of volcanic action and land-subsidence considerably to the southward of Iceland, the line of this action as shown by the geological formation of Iceland itself, and the outlying centres of the recent convulsions alluded to, and, lastly, the drift of volcanic particles in a southerly and south-westerly direction, it seems far from improbable that the subsidence of the tract under notice may have resulted from similar agencies.

In some of the old charts, a dangerous reef or shoal, frequently referred to by the navigators of those days as the "sunken land of Buss," is laid down in lat. 57° 30′ N., long. 29° 50′ W. In a finely executed French chart, dated

Paris, 1777, by M. Fleurieu, this position is assigned to it; and in the same chart we find another shoal put down considerably to the eastward, namely, in lat. 59° 30′ N., long. 16° 50′ W., that is to say, about fifty or sixty miles from the north-western portion of the Rockall Shoal. Captain Sir J. Ross* alludes to both these shoals in the narrative of his voyage in 1818. He writes, "We came, "on the 8th of May, to a spot where a bank is laid down in Steel's chart as dis- "covered by Olof Kramer" (lat. 59° 28′, long. 17° 22′); "but we could find no "soundings in 130 fathoms, anywhere on or near the place." And again, "At "noon we found ourselves exactly in the latitude of the sunken land of Buss, as "it is laid down in some charts, namely, 57° 28′ N.; and being desirous of deter- "mining whether such a bank really existed in long. 29° 45′, we altered our "course for the purpose of ascertaining the fact." "At sunset, being near the "spot, shortened sail and hove to, in order to sound; but no bottom was found "in 180 fathoms. Our sounding was repeated every four miles, with no better "success."

In Captain Graah's narrative of a voyage to Greenland in 1828†, he says, "On the 25th we passed what is laid down in the charts under the name of the "Sunken-land-van-Buss—a danger made mention of even in the latest English "Sailing Directions, but which mariners may be now assured is altogether an "imaginary one. It is, by the way, remarkable enough, that precisely where the "Sunken-land-van-Buss is thus laid down, the ancient charts place Frisland, that "mysterious land which geographers have been so puzzled where to look for, "and which but very lately has been ascertained to be no other than the "Faröe Islands. This very erroneous location of Frisland serves, in my opinion, "to prove that Zeno (the Venetian navigator of the 14th century) was far from "having that intimate and accurate knowledge of our Northern Seas which "many give him credit for."

In the appendix to the same work, reference is made to "Ivar Bardsen's". Sailing Directions for navigating between Iceland and Greenland, which describe some rocks under the name of "Gunbiörn Skerries" as situated to the south-

* Voyage of Discovery made in H.M.S. 'Isabella and Alexander,' for the purpose of exploring Baffin's Bay, &c, by Sir John Ross, Capt. R.N. London, 1819, pp. 11 and 14.

† Narrative of an Expedition to the East Coast of Greenland, by Captain Graah, Royal Danish Navy. Translated from the Danish. London, 1837, p. 20.

westward, exactly midway between Iceland and Greenland, and recommend that a particular course should be steered in order to avoid the ice that had drifted down and "set itself fast" to these skerries. • From what is above quoted, it will however be evident that Captain Graah discredited the existence of these skerries.

Mention is also made of land in this locality in Crantz's 'History of Greenland*.' In speaking of Sebastian Cabot as having been the first to penetrate into Davis Straits in 1497, Crantz adds, "A century before this, in 1380, we "read that Nicolas and Antonius Zeni, two noble Venetians, were carried off by "a storm from the coast of Iceland into the Deucaledonian Sea; and that in "lat. 58°, between Iceland and Greenland, they discovered a large island "inhabited by Christians, and covered with a hundred towns and villages, which "was called *West Friesland*. Since that time, however, we have not a syllable "of intelligence which can give an air of truth to this story. Frobisher in his "third voyage touched at a country in that latitude, and found the inhabitants "similar in all respects to the Greenlanders, whence he justly concluded that it "was a part of Greenland. Some persons, however, espouse the opinion that "this island has been swallowed up by an earthquake, and is the same with the "sunken land of Buss, marked on the charts, and which is dreaded by seamen "from the shallowness of the incumbent water and the furious dashing of the "waves."

Without further multiplying the statements of the older writers on this subject, I think, notwithstanding the utter distrust with which they have been regarded, that there is quite sufficient evidence in the distinct declarations of the Venetian and Norwegian navigators, coupled with those of later voyagers who speak of a shoal or *sunk land*, and the remarkable confirmation afforded by the recent soundings, to establish the probability that a tract of land or island did once exist between the 27th and 29th degrees of N. latitude and the 59th and 60th degrees of W. longitude, and that it was either submerged suddenly by some tremendous volcanic action, or subsided slowly, leaving behind only the shoal which is now completely hidden below the surface.

According to present information, the isolated fact is established, that about midway between the 27th and 32nd degrees of W. longitude, where on the one side the depth is 1160 fathoms, and on the other 1260 fathoms, the water shoals

* 'History of Greenland,' from the German, by David Crantz. London: 1820, p. 250.

to 748 fathoms. Judging from the contour of the Atlantic basin, and the known course of the Gulf Stream, which at the present day sweeps directly along this 200-mile longitudinal tract, an increase and not a decrease of depth might naturally have been expected. It is necessary for me to state that the selection of the spot at which the 748-fathom sounding was taken bore no reference whatever to the question now at issue, but rather to the extreme difficulties attending the operation of sounding at all during the tempestuous weather the ship encountered, and that such decrease in depth was wholly unlooked for: and hence, although the allusion to such a depth as being shoal water may appear somewhat inappropriate, it must be borne in mind that nothing could be more unlikely than that a spot so selected should represent the shallowest water, or that we should find least depth at two degrees northward of the point indicated in the old charts, and which, if it ever existed as dry land, must have been the most elevated and therefore the last submerged portion of the tract in question.

When we take into consideration that Sir John Ross sounded only to a depth of 180 fathoms without striking bottom, and that until a very recent date the idea of systematically surveying depths estimated by thousands instead of hundreds of fathoms was never entertained, it becomes easy to account for the failure of those navigators who deny the existence of any submerged land, to trace either its position or its boundaries.

It is much more probable that spots occur along this submerged tract on which the depth of water is reduced far below that indicated by the sounding, than that the shallowest point should have been accidentally struck; and even supposing that no very considerable diminution should be met with, and that it becomes necessary to assume a subsidence of several hundred feet at the spot last submerged, the case would by no means be without parallel. On the contrary, taking as our examples Sweden in the one direction, and Greenland in the other, ample geological evidence can be adduced to prove that gradual elevation in the one case, and gradual subsidence in the other, have been and continue in operation. In Sweden, we find that land now elevated several hundred feet above the present sea-level must once have constituted the bed of the ocean. Were it possible to observe the traces of ancient water-levels on the now submerged slopes of the Greenland fiords, the evidence would, no doubt, show that depressions, equalling in degree any that may be considered necessary

in order to account for the "sunken land" under notice, have taken place, not under the operation of sudden volcanic convulsions, but as the result of a gradual process acting uninterruptedly through vast periods of time. It is somewhat singular that Captain Graah, who was the foremost to repudiate the idea of an island or shoal having existed in the locality assigned to it, should, in 1823, have been the first to notice the extensive subsidence that had taken place along the western shores of Greenland*.

Lastly, it must not be forgotten that, within the memory of man, one if not two islands have been raised up out of the sea, and again submerged, off the south-west coast of Iceland, in a line which, if extended, would very nearly intersect the position assigned to the "sunken land of Buss;" and although, as before stated, active volcanic disturbance is not requisite to produce the effect in question, there is more likelihood of its taking place in regions subject to such disturbances than in regions never under this influence.

I shall have occasion, in a future chapter, to draw attention to the evidences afforded by certain creatures, whose normal habitats are in comparatively shallow zones, having become acclimatized, perhaps through a long series of generations, and rendered capable of maintaining existence at depths vastly in excess of those which may be regarded as normal in other latitudes. One example is drawn from the west coast of Greenland, in lat. 64° 14′ N.; the other from a point about midway between the most southern part of Greenland and Rockall, in lat. 59° 27′, long. 26° 40′ W. In now drawing attention to these two cases, I am desirous of showing that, irrespective of the facts already noticed, there are circumstances which render it probable that subsidence has taken place, and is still taking place, along the tract in question, and, further, that the line of subsidence between South Greenland and Rockall, thus indicated, tallies in a very remarkable manner with the ancient boundary line suggested by Sir John Richardson, and acquiesced in by the late Professor Edward Forbes, on independent grounds, as marking the northern limit of the Atlantic at the period at which it was separated from the great Arctic basin. In the concluding portion of 'The Natural History of the European Seas,' Mr. R. Godwin-Austen thus describes the boundary in question:—"A line from Newfoundland to Cape "Farewell, thence across the Atlantic of Iceland and the Faröe Archipelago,

* See Sir Charles Lyell's 'Principles Geology.' London, 1853, p. 530.

"represents, conjecturally, the northern limitation of the Atlantic at the time "when it did not communicate with the Arctic basin*,"—thus lending a powerful confirmation to the view I have endeavoured to establish.

At the present time, when the attention of naturalists is directed to the evidences of the community of types ascribable to the animals and plants of Europe and the North American Continent, and the question to be decided is whether the ancient communication between these two countries was effected across the North Atlantic or North Pacific Oceans, it is of the utmost consequence that every fact likely to throw light upon it should be made public. Under this impression I have been induced to exhume the evidences above cited, and to append my reasons for inclining to a belief that the tract over which the 'Bulldog' sounded may have formed, in ages gone by, one of the stepping-stones which connected the eastern and western hemispheres of the globe.

It has been stated that two of the soundings taken since the 'Bulldog' entered on the survey of the direct route between Cape Farewell and Rockall have proved of high interest. The first of these, which indicated 748 fathoms in a part of the North Atlantic basin at which we might reasonably have expected to find an increase instead of a diminution in depth, has already been noticed. The second can only be cursorily touched upon in this place, inasmuch as it involves the entire question of life at extreme depths in the sea, and must therefore be discussed at length hereafter. This sounding far exceeds in importance any previous sounding on record; for not only does it for ever determine the fact that animal existence may be maintained at depths vastly greater than by most persons has been believed possible, but it proves the fallacy of several of the conditions which have heretofore been supposed to limit the bathymetrical distribution of animal life, and points to the existence of a new series of creatures peopling the deeper abysses of the ocean, and destined, perhaps, to furnish many of the missing links between the submarine faunas of the Past and Present. That single sounding, I may be permitted to say, compensates for every disappointment that weather and accident may previously have engendered. At the eleventh hour, and under circumstances the most unfavourable for searching out its secrets, the deep has sent forth the long-coveted

* 'The Natural History of the European Seas,' by the late Professor Edward Forbes, F.R.S. Edited and continued by R. Godwin-Austen, F.R.S. London, 1859, p. 286.

message. What mechanical ingenuity failed to achieve, hunger or curiosity accomplished; and thus whilst the sounding-apparatus only succeeded in bringing up from a depth of 1260 fathoms a number of minute shell-covered creatures, so simply organized as to render them incapable of perceiving or escaping a danger, thirteen star-fishes, ranging in diameter from 2 to 5 inches, came up convulsively embracing a portion of the sounding-line which had been paid out in excess of the already ascertained depth and rested for a sufficient period at the bottom to permit of their attaching themselves to it. These star-fishes arrived at the surface in a living condition, and, what is still more extraordinary, continued to move their long spine-covered rays for a quarter of an hour afterwards—clearly proving that, if their adherence to the sounding-line was due, in the earlier stage of their progress upwards, to a clonic spasm of the muscular tissue, neither life nor nervous energy ceased till after the lapse of the period mentioned.

This sounding, taken at a distance of about three degrees to the eastward of the position at which a depth of 748 fathoms was met with, indicates an increase of 572 fathoms, or about 150 fathoms in excess of the depth ascertained at the same distance in the westward direction. The discovery of the star-fishes in this situation, although it can in nowise detract from the validity of the fact regarding the presence of living creatures at the greatest depths, may nevertheless be associated in some measure with the subsidence of the sea-bed, inasmuch as, during the lapse of ages, the successive descendants of the star-fishes that originally inhabited the shallower waters present before such subsidence took place may, by degrees, have become capable of maintaining their existence under the now altered conditions. Whether this has or has not been the case must unfortunately remain for ever a matter of mere speculation; but, supposing it to have been so, it would only tend to prove that, in certain instances, transitional habits may be acquired without producing transitional characters; and if the possibility of animal life at extreme depths be admitted (as I take for granted it must be henceforth), it is just as reasonable to assume that the ancestors of animals now capable of existing in shoal water may have lived originally at extreme depths, the one transition being in nowise more wonderful than the other. The hard-shelled Echinoderms are constituted for creeping, and not for swimming; and hence, if it could be shown that any of them (such as *Palmipes*,

for example) are capable of floating or swimming, the case would at once be altered, and there would be fair ground for assuming that, whilst their ancestors originally belonged to the free-rayed group and inhabited great depths, the descendants of these had by degrees developed the membrane-like expansion between the rays in order to enable them to remove to shallow water on the subsidence of the sea-bed. It is well known, however, that neither *Palmipes* nor any of the other hard-shelled Echinoderms are floating animals; and accordingly the proof that those brought up by the sounding-line actually travelled from the bottom, and not from some superincumbent stratum of water, must be regarded as conclusive. It is only necessary to add that the nearest point of Iceland to the spot at which the sounding was taken is 250 miles distant, whilst between it and the nearest point of Greenland the distance is 500 miles.

Throughout the day large flocks of Dovekies have flown across in a south-westerly direction, as if migrating from Iceland to Newfoundland or the southern portion of Labrador. Measuring from the nearest point to point of land, these birds would have to traverse a distance of 1200 miles, which, at a speed of thirty miles an hour, would involve forty hours' incessant flight. Although migrations across even greater areas of open sea are known to be effected by many species of purely aquatic birds, it becomes difficult to conceive how small wading birds, such as the Sandpipers, can accomplish a similar journey. A number of the latter, in pairs, flew past, taking the same course; but, from the manner in which they invariably hovered round the ship for a short time, as if anxious to alight even at this early stage of their voyage, it would almost seem probable that their instincts had been at fault when they selected their route. Should this be the case, and the circumstance I have mentioned be one of frequent occurrence, very large numbers of these birds must perish annually in the middle of the sea, their soft parts being gradually devoured by the countless great and small zoophagists that inhabit its waters, whilst their skeletons subside and become ultimately entombed amongst the deposits at the bottom.

Oct. 19.—Rekiavik. After having encountered a continuous succession of the heaviest gales since leaving Greenland, the 'Bulldog' once more anchored here this afternoon, in order to coal and repair damages.

In approaching Cape Rekianess last night, about 11 P.M., we passed close by an isolated basaltic rock, known as the "Blinde Skier," or "Grenadier's Cap,"

which rises up perpendicularly from the sea to the height of 80 feet. It is a curious fact, that both this rock and one of a similar kind on the Rockall shoal present so close a resemblance to a ship under sail, that it is almost impossible to believe they are anything else, when seen from certain points of the compass. By a sounding taken at a distance of about a quarter of a mile from the "Blinde Skier," the bottom was shown to consist of coarse basaltic sand and shell-débris. The period at which this rock was heaved up is unknown; but there can be no doubt of its having maintained its present position unmoved for centuries, during which both the mainland of Iceland and the intervening portion of the sea-bed have undergone several very severe convulsions. Thus in 1783, the year in which the most tremendous disturbances on record took place in Iceland, a submarine volcano burst into action in lat. 63° 25′ N., long. 23° 44′ W., at a distance of ten or twelve miles from the Blinde Skier rock, and thirty miles to the south-westward of Cape Rekianess, during which an island of considerable size and height was thrown up. This island was named "Nynoë," or the New Island, and claimed by the King of Denmark; but, before a year had elapsed, it again subsided, leaving nothing but a sunken reef to indicate its position. In 1830 a smaller island was ejected, somewhat nearer to the coast; but it was in like manner submerged after a brief interval.

Oct. 28.—Today the 'Bulldog' again proceeded to the southward with a view to continue the line of soundings between the point at which she diverged *en route* to Iceland and Rockall.

From a few soundings taken between Rekianess and the Blinde Skier, it appears that the obsidian-like detritus, of which mention has been made in Chapter II., commences somewhat to the eastward of the latter, and stretches to the north-westward in a belt of about twenty miles in diameter, fringing the western shore of the promontory; whilst to the westward of this, and running parallel with it, a belt of rolled basaltic drift ascends and crosses the first line of soundings, as formerly indicated. Although no data were afforded, during the outward voyage between Iceland and Greenland, for determining the source from which the rolled fragments of basalt were derived, these latter soundings prove that the belt in question is borne northwards by the eastern margin of that portion of the Gulf Stream which splits on coming across the Blinde Skier shoal, ascends in a northerly direction towards Faxe Fiord, and then sweeps up the

west side of Iceland. This ascending current, it may be observed, would operate continuously along the whole of this shoal-water tract, irrespectively of the ordinary tidal current, which can only affect the superficial stratum of water. Under any other circumstances, inasmuch as it has already been shown that this tract has been under the immediate influence of recent volcanic convulsions, the belt of basaltic gravel, or, at any rate, that portion of it in the vicinity of the Blinde Skier which has altogether escaped such volcanic action, must have been buried under a similar obsidian-like deposit. Should a telegraphic cable ever be carried along the North-Atlantic route, there is good ground for believing that the surest method of avoiding the danger of submarine volcanic action, to which the greater portion of the southern district of Iceland is liable, would be to bring the wire across from Ireland, *viâ* Rockall, to the Blinde Skier, and thence direct to Labrador. If injury from volcanic disturbance were to take place at all in the case of a wire following this route, it would in all probability occur between the Blinde Skier and the mainland, to which there might be a short branch-line, and not between the Blinde Skier and Labrador, as no recent volcanic action has been known to take place in that direction.

Nov. 11.—The few remaining soundings having been concluded in defiance of a still further continuance of stormy weather, and the supply of coal being again exhausted, the 'Bulldog' today put into Killibegs, County Donegal. At that port I left the ship and bade adieu to my messmates, whose friendly companionship I shall always recollect with feelings of sincere pleasure.

PART II.

THE BATHYMETRICAL LIMITS OF ANIMAL LIFE IN THE OCEAN.

ON no question connected with marine zoology does the information of naturalists appear to have been so singularly defective as on the bathymetrical limit of animal life in the ocean. When it is borne in mind that, until a very recent period, but a few isolated attempts had been made to bring up "specimens of bottom" from deep water, and that the "antibiotic view" rested exclusively on the foregone conclusion that no organized creature "of a kind analogous to those with which we are acquainted" could exist under the extraordinary conditions of pressure, aëration, temperature, and light which prevail on the deep-sea bed, it can hardly be wondered at that the clearest proofs should have been necessary in order to establish an opposite opinion. But it is nevertheless surprising that the antibiotic view, based as it was altogether on negative evidence, should have remained unimpugned for nearly half a century after the publication of statements which, although meagre to a degree when considered with reference to the importance of the subject, were calculated to throw reasonable doubt upon it and consequently deserved most serious consideration.

In 1819, the late Sir John Ross published an account of his having obtained in Baffin's Bay various "sea-worms," "shrimps," and other creatures, from depths greatly exceeding those at which animal life was supposed to become extinct; and nearly thirty years subsequently, Sir James Ross also reported having dredged up living creatures from great depths in the Antarctic seas. Hence, whatever weight may have attached to the testimony of these distinguished Arctic navigators on other subjects, it is evident that some deep-rooted

doubt forbade the recognition of statements so opposed to the established views of naturalists, and that nothing but the foregone conclusion already referred to could have led to their being so unhesitatingly ignored. That the presence of animal life at great depths was ignored until the period at which the question was unequivocally set at rest by the capture of the star-fishes on board the 'Bulldog' may be fairly inferred, I think, from the circumstance that, with one exception entirely unconnected with the above observations, no naturalist or physiologist had previously ventured to prove that animal life extends indefinitely below the limit of the deep-coral zone; but, on the contrary, so universal was the assent given, both in Europe and America, to the views propounded by the late Professor Edward Forbes, that, in one of the most recent and authoritative works published on the subject, the belief is unhesitatingly expressed, that, at 300 fathoms below the surface of the sea, life is extinct.

A few extracts from the writings of some of the most eminent authorities on the geographical distribution of marine creatures will suffice to show that, up to the period at which my Notes on the presence of animal life at vast depths in the Ocean * were published (that is, immediately after the termination of the North-Atlantic Cruise in 1860), "the extreme depressions of the sea, like the extreme elevations of the land, were supposed to be barren and lifeless solitudes;" and they will at the same time prove, whatever may have been the value of the data furnished by any previous soundings, that an entirely new series of proofs was rendered indispensable, before the fact of the extension of the bathymetrical limits of life by many hundred additional fathoms could be presented to the scientific public as deserving their credence.

In 'The Natural History of the European Seas †,' Professor Edward Forbes writes as follows:—"Last and lowest of our regions of submarine existence is that of the *deep-sea corals*, so named on account of the great stony zoophytes characteristic of it in the oceanic seas of Europe. In its depths the number of peculiar creatures is few, yet sufficient to give a marked character to it; whilst the other portions of its population are derived from the higher zones, and must

* 'Notes on the Presence of Animal Life at Vast Depths in the Sea.' Taylor & Francis: Lond., 1860.

† 'The Natural History of the European Seas,' by the late Professor Edward Forbes, F.R.S. Edited by R. G.-Austen, F.R.S. London, 1859: pp. 11, 26, and 246.

be regarded as colonists. As we descend deeper and deeper in this region, its inhabitants become more and more modified, and fewer and fewer, indicating our approach toward an abyss where life is either extinguished or exhibits but a few sparks to mark its lingering existence. Its confines are yet undetermined, and it is in the exploration of this vast deep-sea region that the finest field for submarine discovery yet remains." Again, alluding to the entirely new field of inquiry opened out to the naturalist by the investigation of the various provinces of marine life, and the delight experienced by him the first time he "saw the dredge hauled up after it had been dragging the sea-bottom at a depth of more than 100 fathoms," he says, "Fishing-lines had now and then entangled creatures at as great and greater depths, but these were few and far between, and only served to whet our curiosity, without affording the information we thirsted for."

Towards the close of the same volume, Mr. R. Godwin-Austen expresses his adherence to the same opinions, in these words:—"The sublittoral zone of every sea and ocean presents the fulness of its fauna; and from that it decreases progressively and rapidly, till, in regions far within those in which the finer sedimentary deposits are distributed, animal life altogether ceases. Far beyond the zones where the members of a marine fauna *live*, there are areas of wide extent where animals of oceanic habits strew their delicate structures: this is the zone of the 'free-swimmers'—Pteropods, Nucleobranchs, Pelagic Cephalopods, and Crustaceans. The depositions of all past times present every gradation of bathymetrical distribution, down to the 'azoic zones' of depth; and the mere geologist must beware not to misinterpret the evidence presented to him, and suppose that some old world of waters was without life, merely because he finds no traces of it. Still less, on such negative evidence, must he speculate as to the 'dawn of life' and 'primordial zones.' The history of our own seas, and of all seas, teaches us that there is a law of proportion in the classes and orders of the living things that dwell there, and that the presence of one form is safe ground of inference as to the co-existence of countless others."

Sir Charles Lyell, in his remarks on the migrations of the Testacea*, says, "Professor E. Forbes has shown, as the result of his dredging in the Ægean Sea, that there are eight well-marked regions of depth, each characterized by its own testaceous fauna." And again, "a copious list of species is given as characteristic

* Lyell's 'Principles of Geology.' London, 1853: pp. 649 and 773.

of each region down to the seventh, which lies between the depths of 80 and 105 fathoms, all the inhabited space below this being included in the eighth province, where no less than 65 species of Testacea have been taken." In describing the "imbedding of the remains of marine plants and animals," he writes as follows:—"I have already stated that at a depth of 950 fathoms, between Gibraltar and Ceuta, Captain Smith found a gravelly bottom, with fragments of broken shells, carried thither probably from the comparatively shallow parts of the neighbouring straits, through which a powerful current flows. Beds of shelly sand might here, in the course of ages, be accumulated several thousand feet thick. But, without the aid of the drifting-power of a current, shells may accumulate in the spot where they live and die, at great depths from the surface, if sediment be thrown down upon them; for, even in our own colder latitudes, the depths at which living marine animals abound is considerable. Captain Vidal ascertained, by soundings off Tory Island, on the north-west coast of Ireland, that Crustacea, Star-fish, and Testacea occurred at various depths between 50 and 100 fathoms; and he drew up Dentalia from the mud of Galway Bay, in 230 and 240 *fathoms* water."

Mr. Page, in 'The Advanced Text-Book of Geology*,' says that, "according to experiment, water at the depth of 1000 feet is compressed $\frac{1}{340}$th of its own bulk; and at this rate of compression we know that at great depths animal and vegetable life, as known to us, cannot possibly exist,—the extreme depressions of seas being thus, like the extreme elevations of the land, barren and lifeless solitudes. Further, at great depths, sand, mud, and all loose débris will be compressed and consolidated; and, according to the experiments of Sir James Hall, even limestone could be fused without the loss of its carbonic acid. The effect of depth in regulating the distribution of species is one of the prettiest problems in zoology, every zone from the shore seawards being characterized by different specific forms; and, as will hereafter be seen, the comparative depths of seas of deposit may be ascertained with considerable certainty by a study of the fossils found in such deposits."

According to Messrs. Agassiz and Gould†, "The depths of the ocean are quite

* 'Advanced Text-Book of Geology, Descriptive and Industrial,' by David Page, F.G.S. London, 1856: p. 20.

† 'Outlines of Comparative Physiology,' by Professors Agassiz and Gould. London, 1851: p. 365.

as impassable for marine species as high mountains are for terrestrial animals. It would be quite as difficult for a fish or a mollusk to cross from the coast of Europe to the coast of America, as it would be for a reindeer to pass from the Arctic to the Antarctic regions across the torrid zone. Experiments of dredging in very deep water have also taught us that the abyss of the ocean is nearly a desert. Not only are no materials found there for sustenance, but it is doubtful if animals could sustain the pressure of so great a column of water, although many of them are provided with a system of pores which enable them to sustain a much greater pressure than terrestrial animals."

The same distinguished authorities have, at a still more recent date, expressed similar opinions. Mr. Marcou, a member of the Boston Society of Natural History (U.S.), having informed that Society that he had read in an English journal an account of the capture of the star-fishes (as given by me in my published notes, and also in a lecture at the Royal Institution of Great Britain, in February 1861), Messrs. Agassiz and Gould intimated their doubts of the creatures having been brought up from the depth stated, and suggested that they might have become attached to the line at a point far nearer to the surface.

The following passages, quoted from the invaluable work written by Sir Henry De la Beche thirty years ago*, when the researches of Sir John Ross were comparatively speaking of recent date, clearly show the opinions then entertained on the subject:—"We have hitherto considered marine animal life with reference to creatures living in particular depths of water, and which, when we regard those of the ocean, are comparatively shallow. The surface of the deep ocean teems with animal life, and is probably not less well proportionably tenanted down to depths where, from the want of the necessary conditions, it ceases to exist. . . . What the actual depth may be beneath which animal life does not exist in the ocean, we have yet no good data for ascertaining; but that there must be such a limit, to at least any kind of life analogous to that with which we are acquainted, there can be little doubt."

Professor Löven, in discussing the bathymetrical limits of submarine life in the Scandinavian seas†, alludes to three forms of Echinoderms living in the

* 'Researches in Theoretical Geology,' by H. T. De la Beche, F.R.S., &c. &c. London, 1834: pp. 262, 263.

† British Association Reports, 1844, vol. xiii. p. 50.

deep-coral zone as low down as the fisherman's line can be sunk, and adds, "As to the point at which animal life ceases, it must be somewhere; but with us it is unknown. As the vegetation ceases at a line far above the deepest regions of animal life, of course the zoophagous mollusca are altogether predominant in these parts, whilst the phytophagous are more peculiar to the upper regions."

And lastly, Professor Phillips, in a very recent work on the 'Origin and Succession of Life on the Earth*,' sums up what was known regarding the "influence of depth on the distribution of life in the sea" with this observation—"That it appears that the relative fertility of the several zones decreases towards zero; and it is believed that at 300 fathoms life is extinct."

Having thus shown how universally the opinion has been entertained that animal life is limited to depths which vary slightly in different localities with the downward range of the deep-coral zone, I would now direct attention to the nature of the evidence that has hitherto been adduced in support of an opposite view, by three writers whose names will always be associated with great scientific discoveries in their respective departments, namely, Sir John Ross, Sir James Ross, and Professor Ehrenberg.

In order to remove all doubt as to the value of the data furnished by Sir John Ross's soundings in 1818†, I subjoin such extracts from his work as bear at all on the subject, premising that, out of 59 soundings at depths exceeding 100 fathoms, 23 ranged from 270 to 1050 fathoms,—the apparatus employed being the "deep-sea clams" specially designed by Sir John Ross for deep-sea dredging.

On the 31st of August, lat. 74° 03′ N., long. 81° 28′ W., he writes as follows:—"About six it fell nearly calm for a short time, and we sounded with the deep-sea clams, which brought up a quantity of mud, in which were five worms of a species that had not been seen before. There were only 650 fathoms of line out, consequently there could not be more than that depth of water; but there might have been much less, which was probably the case, as the swell was so great that it was uncertain, after 200 fathoms, when the machine reached the bottom."

* 'Life on the Earth, its Origin and Succession,' by John Phillips, M.A., LL.D., F.R.S., &c. &c. London, 1860: p. 16 *et seq.*

† 'A Voyage of Discovery for the purpose of Exploring Baffin's Bay,' by Sir John Ross, K.S., Royal Navy. London, 1819: vol. i. pp. 247, 251, and vol. ii. pp. 5, 49.

On the 1st of September, lat. 73° 37′ N., long. 75° 25′ W., it is stated that "soundings were obtained correctly in 1000 fathoms, consisting of soft mud in which there were worms; and entangled on the sounding-line, at the depth of 800 fathoms, was found a beautiful Caput Medusæ: these were carefully preserved, and will be found described in the appendix*."

On the 6th of September, lat. 72° 23′ N., long. 73° 07′ W., "At six, it being quite calm, and the water smooth, we sounded with the deep-sea clams, and found 1050 fathoms, which were the deepest soundings ever reached in Baffin's Bay. As we had only 120 fathoms fifteen miles further north, it is evident that the bottom of the sea, like the land, must here be very mountainous. The mud at the bottom was so soft that the instrument was completely buried, and it required considerable force to draw it out. The sea being a dead calm, the line was perfectly perpendicular, and we had a good opportunity of obtaining the exact depth before it started out of the ground. The instrument came up completely full, containing about six pounds of mud, mixed with a few stones and some sand. This mud was much coarser than that which we had before obtained, and was also of a much looser nature. When the line came up,

* The whole information furnished in the appendix with reference to the organisms procured in these soundings is given below—

"Class CRUSTACEA.

Genus HIPPOLYTE, Leach.

Species.—Having mislaid the specimen, I cannot give a description of it.

Genus GAMMARUS, Latreille.

Species *Sabini*.—Segmentis dorsalibus postice falcato-productis. Baffin's Bay. Captain Sabine.

Class ANNELIDES, Cuvier.

Genus NEREIS, Linné.

Species *Phyllophora*.—Ore edentulo, pedibus basi lamellis foliosis instructis. Baffin's Bay.

Genus LEPIDONOTUS, Leach.

Species *Rossii*.—Pedibus densissime testaceo hirsutis, squamis dorsalibus cærulescente-griseis. Baffin's Bay, amongst soundings.

Type RADIATA.

Class ECHINODERMATA.

Genus GORGONOCEPHALUS, Leach (1815). EURYALE, Lamarck (1816).

Species *Arcticus*.—Corpore supra glabro, radiatim costato, costis tuberculatis; radiis longissimis, tenuibus, supra granulatis, articulis (apicalibus præsertim) distinctissimis. Expansion 2 feet. Baffin's Bay. Captain J. Ross."

a small star-fish was found attached to it, below the point marking 800 fathoms."

And lastly, on the 2nd of October, lat. 62° N., long. 62° 25′ W., "Before noon it fell calm and became foggy. We sounded in 650 fathoms, and obtained from the bottom several small stones and shells." In the table of soundings in the appendix it is mentioned that "Serpulæ, shrimps, and fragments of shells" were contained in this material.

If we bear in mind that the maintenance of animal life has been held to be impossible at great depths, on account of certain physical conditions which have been clearly and repeatedly laid down, we can readily understand why these bare statements should have been disregarded; for, on carefully weighing the evidence they supply, it will be found, whilst no facts whatever are advanced to show the fallacy of the received opinions concerning the bathymetrical limits of marine life, that the whole of the details bearing on the vitality or otherwise of the creatures brought up are withheld; and, moreover, it is irreconcilable with what we know of the habits and structure of the Echinoderms to suppose that the "Caput Medusæ" (Euryale) and "small star-fish" referred to could have been found free-floating and alive at a distance of 200 fathoms from the bottom.

In Sir James Ross's Voyage to the Antarctic regions between the years 1839 and 1843*, the following passage occurs:—"January 19, 1841. Becalmed for two or three hours after noon; the dredge was put over in 270 fathoms water, and after trailing on the ground for some time was hauled in." After detailing the characters of certain pieces of rock brought up, and which are stated to have been deposited probably by an iceberg, he continues, "Besides this there were a great many stones of various kinds of granitic and volcanic structure; but the most remarkable circumstance was drawing up from so great a depth beautiful specimens of living coral, which naturalists and geologists have hitherto concurred in believing unable to work beyond the pressure of a few fathoms below the surface. Corallines, Flustræ, and a great variety of marine invertebrate animals, also came up in the net, showing an abundance and great variety of animal life. Amongst them I detected two species of Pycdogonum; Idotæa

* 'A Voyage of Discovery in the Southern and Antarctic Regions,' by Captain Sir James Clark Ross, R.N., K.N.T., F.R.S., &c. &c. London, 1847: vol. i. p. 201 *et seq.*

Baffini, hitherto considered peculiar to the Arctic seas; a Chiton, seven or eight bivalves and univalves, an unknown species of *Gammarus*, and two kinds of Serpula adhering to the pebbles and shells." After stating that an account of these, by Charles Stokes, Esq., appears in the appendix, he adds, "It was interesting amongst these creatures to recognize several that I had been in the habit of taking in equally high northern latitudes; and, although contrary to the general belief of naturalists, I have no doubt that from however great a depth we may be enabled to bring up the mud and stones of the bed of the ocean, we shall find them teeming with animal life; the extreme pressure at the greatest depth does not appear to affect these creatures; hitherto we have not been able to determine this point beyond a thousand fathoms, but from that depth several shell-fish have been brought up with the mud"*.

It will thus be seen that Sir James Ross alluded to Sir John Ross's sounding taken in 1819, when he referred to "shell-fish" having been obtained with the mud from a depth of a thousand fathoms,—there being no prior sounding described by him as taken in the Antarctic regions, in which living creatures were brought up at as great a depth as 270 fathoms, although subsequently Crustacea were brought up from 400 fathoms. I should not have deemed it necessary to point out the misconception which has arisen on this subject, had it not become general. Thus Mrs. Somerville declares†, in language distinctly denoting its reference to this sounding, that "before Sir James Ross's voyage to the Antarctic regions, the profound and dark abysses of the ocean were supposed to be entirely destitute of animal life; now it may be presumed that no part is uninhabited, since during that expedition live creatures were fished up from a depth of 6000 feet." In attempting to reconcile these

* Under the head of "Remarks on some corals obtained from great depths in the Antarctic Ocean," in a letter from Charles Stokes, Esq., F.R.S., in the appendix to Sir John Ross's work, Mr. Stokes, after alluding to a previous sounding at 400 fathoms, in which none of the shells and corals "appear to have been brought up in a living state," enters into a description of the organisms obtained in the sounding to which the above extract refers, and states that a small piece of "Retepora cellulosa," and a "Retepora or Hornera" resembling "H. frondiculata" of Lamouroux, were evidently taken in a living condition, adding his surprise at these and certain other organisms having been found, "except in a warm climate and at a small depth," and antithetically pointing out the occurrence of living specimens of a species of "Premnoa" at from 150 to 300 fathoms on the coast of Norway. (Appendix to Sir James Ross's work, vol. i. p. 334 *et seq.*)

† 'Physical Geography,' by Mary Somerville. London, 1851: vol. ii. p. 246.

facts, I desire to do justice both to Sir James Ross, who unquestionably perceived the full force of Sir John Ross's researches, and to Mrs. Somerville, who, in defiance of the unbelief of "naturalists and geologists," recognized the all-pervading principle of life where its presence had been so long and so obstinately repudiated.

In the portion of this work specially devoted to the history of the Rhizopods, I shall have occasion to state in detail my reasons for differing, on many very important points, from an authority to whom all who have studied the minute forms of the animal and vegetable kingdoms must look up with deference. At present I would merely observe that, whilst I am fully convinced of the vitality of the organisms to which Professor Ehrenberg refers, even at the extreme depths at which they are occasionally found, I cannot for a moment subscribe to the opinion that such vitality is demonstrated, as he most distinctly asserts it to be, by the presence of the soft parts contained within their shells. There are several strong collateral reasons for assuming that they normally live at the bottom; but when all these are added together, it still remains impossible to say that the fact is fully substantiated. It is far from improbable that the only absolute proof by which the question can be determined may yet be obtained—namely, that which would be afforded by distinct vital movements in the organisms after reaching the surface. For, if it is possible for creatures of a much higher type of structure to retain their vitality (as I shall presently show to be the case) after being brought up from equally vast depths, we are fully justified in assuming that creatures of such a simple type as the Foraminifera and Polycystina may retain their vitality under similar circumstances. If we turn to the evidence afforded by the fossil forms of these lower organisms, we find abundant reason for believing them to be fitted to undergo, with impunity, changes in the conditions by which they are surrounded far greater than could be borne by organisms of a higher order. Thus, it is well known that they command not only a much wider geographical range, both as regards recent and fossil forms, but that species living at the present day extend back to periods infinitely more distant in the world's history. But, whatever degree of probability may attach to the opinion that the Foraminifera and Polycystina of the soundings live and multiply at the depths from which the sounding-machine occasionally brings them, we must never lose sight of the fact that between probability and proof

there is a wide difference, and that, whilst the one may be said to be established on much stronger grounds than that adduced by Professor Ehrenberg, the other still remains to reward some patient labourer in the domain of microscopical natural history.

The presence of the sarcode, apart from other evidence, proves nothing beyond the powerful preservative effects of sea-water, surcharged, under a stupendous pressure, with its saline constituents. I have at the present time Foraminifera obtained, in a living condition at a depth of 100 fathoms, five years ago. These are, as a matter of course, dead; yet they retain their sarcode unchanged in quantity, in bulk, and in colour, and differing only from recent living sarcode in a somewhat diminished degree of viscidity. The pure Globigerina-deposits of the North Atlantic, obtained a year and a half ago, in like manner retain their sarcodic contents equally unchanged. It is highly probable, for reasons hereafter to be adduced, that these also were alive when taken at the bottom; but it is equally certain that they are dead now, and that they have been so, at all events, since a very brief period after they quitted their native element. It is necessary to mention these circumstances, inasmuch as Professor Ehrenberg has not only based the vitality of the Foraminifera, Polycystina, and Diatomaceæ on this single character, but has maintained that vitality has been retained by some of these organisms for several years, during which they had been preserved in closed bottles.

In a paper communicated to 'The Annals and Magazine of Natural History,' in 1844*, "On Various Materials obtained from the Residue of Melted Pancake-ice in the South Polar Regions," the statements on these points are so remarkable and explicit that it is necessary to quote them. After giving a list of "Siliceous Polygastrica" (Diatomaceæ and Polycystina), "Siliceous Phytolitharia" (principally Sponge-spicules), and "Calcareous Polythalamia" (Foraminifera), it is stated that, "In several forms of the genus *Coscinodiscus* their green *ovaries* were recognizable; consequently they must have been alive." And again, with reference to the residue of another specimen of similar material from those regions, containing "Siliceous Polygastrica and Siliceous Phytolitharia," Professor Ehrenberg says, "These and the former specimens were sent over in

* "On Microscopic Life in the Ocean at the South Pole," by Professor Ehrenberg, 'Annals and Magazine of Natural History' (London, 1844), vol. xiv. p. 169 *et seq.*

bottles of water. They were the same sealed bottles in which they were collected in the year 1842. In the first bottle, in which the sediment was considerable, almost every atom being a distinct siliceous organism, *Hemiaulus antarcticus* predominated. The larger bottle of the second mass had allowed the greater part to leak through the sealed cork, so that only about a quarter remained. The mass of sediment arrived in Berlin in 1844, almost all in such a condition that the author had no hesitation on considering them still alive, although they all belonged to the almost or perfectly motionless forms. The Fragillarias" (Diatoms) "predominated; these, though rarely adherent in chains, had their green ovaries mostly preserved in a distinct natural disposition: *Coscinodisci* and *Hemiaulus* also often exhibited groups of green granules in their interior. No movement."

It will be noticed that a great portion of the organisms grouped together under the designation of "Siliceous Polygastrica" are referred by other writers to the vegetable kingdom; these, although not strictly falling within the scope of the present observations, nevertheless illustrate the point under notice, namely, what ought and what ought not to be accepted as proof of vitality in the Protozoa as well as the Protophyta.

The annexed extract from a letter of Professor Ehrenberg's to Captain Maury, dated "Berlin, October 1857"*, shows that the same views continue to be upheld by that indefatigable observer. Addressing Captain Maury, he says, "In your memoir, published by the Geographical and Statistical Society of New York, I see that you have followed the judgment of the old observers, who deny the existence of stationary life at great depths, and who sustain themselves of late by the observations of Mr. Forbes. Also Mr. Bailey has of late published similar opinions. I cannot agree with this antibiotic judgment, after having put it beyond doubt that the greater part of the small calcareous carapaces is filled with small soft bodies; Mr. Bailey also speaks of his observation of these soft bodies in the *Siliceous Bacillaria*, which strengthens my own remark. That the great compression prevents putrefaction is a hypothesis; but the existence of the soft bodies is a certain observation.

"The other argument for life in the deep, which I have established, is the surprising quantity of new forms which are wanting in other parts of the sea. If

* Maury's 'Sailing Directions,' 8th edition. Washington, 1857: p. 175.

the bottom were nothing but the sediment of the troubled sea, like the fall of snow in the air, and if the biolithic curves of the bottom were nothing else than the product of the currents of the sea which heap up the flakes similarly to the glaciers, there would necessarily be much less of unknown and peculiar forms in the depths. The surface and the borders of the sea are much more productive and much more extended than the depths; hence the forms peculiar to the depths should not be perceived. The great quantity of peculiar forms and of soft bodies existing in the innumerable carapaces, accompanied by the observation of the number of unknowns, *increasing with the depth*,—these are the arguments which seem to me to hold firmly to the opinion of stationary life at the bottom of the deep sea."

It is at all times a difficult and an ungracious task to endeavour to demonstrate the fallacy of the views of others, but it becomes tenfold more so when the author of those views holds such an eminent position as Professor Ehrenberg. In the present instance no middle course is left open to me, inasmuch as, disagreeing in almost every fundamental particular regarding the nature, the structure, and the functions of the lower tribes of organisms met with in the oceanic deposits, I am compelled not only to adduce the data on which my own opinions are founded, but to show why I decline to subscribe to opinions that are diametrically opposed to them.

One of our foremost naturalists and comparative anatomists has characterized the researches of Professor Ehrenberg as "wonderful monuments of intense and unremitting labour, but at least as wonderful illustrations of what zoological and physiological reasoning should *not* be;" and has declared it to be "a matter of duty, on the part of those interested in the progress of zoology, to pronounce decidedly against the statements contained in the 'Infusionsthierchen,' so far as regards anatomical or physiological facts"*. I can only appeal to the opinions I have quoted, and the data on which they have been based, in support of the course it has thus been rendered imperative on me to pursue.

Before closing this portion of my subject, it remains for me to draw attention to the very singular fact that whilst Professor Ehrenberg, in common

* 'Annals and Magazine of Natural History,' 2nd series, vol. viii. p. 436: Professor Huxley on the genus *Thalassicolla*.

with many of the other authorities whose opinions have been cited, completely ignored the researches of Sir John Ross, published more than twenty years previously (it being distinctly stated in Professor Ehrenberg's communication to the 'Annals and Magazine of Natural History,' from which the last extracts have been made, that 190 and 270 fathoms were "the greatest depths that had" previously to 1844 "been sounded"), not one of those writers has, up to the present hour, recognized the validity of Professor Ehrenberg's reasoning with reference to the vitality of creatures belonging to the very lowest type, and therefore much less likely to be affected by conditions which they contend would prove fatal to creatures of a higher order.

Having thus placed before the reader the grounds on which naturalists have heretofore regarded the deeper abysses of the ocean as unfitted for the support of animal life, and having endeavoured to state fairly the value of the evidence adduced by the only two observers whose researches have been directed towards the establishment of an opposite view, I have now to draw attention to the physical conditions by which the geographical distribution and the duration on the earth of marine creatures are determined, and to the various influences which, in conformity with the most recent discoveries, appear to regulate their bathymetrical range.

It would be foreign to the purpose of the present inquiry to state the various arguments by which the theory of transmutability of species and the doctrine of specific centres of creation have been maintained by their respective supporters. It is sufficient to know that, commencing from an assumed period in the earth's history, no matter how remote from "the beginning," certain forms were grouped together within fixed geographical areas, each of which was already distinguished by typical characters. Were it possible to define this period, or to adopt a cotemporaneous starting-point for every group of animate forms on the surface of the globe, whence to calculate the amount of divergence or specific differentiation its several species had undergone, the task of determining which hypothesis is true and which false would be comparatively easy. But, in the absence of such a fixed point, it only remains for us to draw our inferences from well-marked modifications in the characters of well-known species, and endeavour to reconcile these modifications with such altered conditions of the earth's crust as we can prove to have accompanied them.

When we consider the changes which are continuously and yet almost imperceptibly going on in the distribution of land and sea, and bear in mind that, although the periods occupied in the completion of these are inconceivably vast, they are insignificant in comparison with epochs in the world's history anteriorly elapsed, we shall understand how gradual must be the operation of causes by which the characters of species are modified and their disappearance from the earth eventually brought about. Were it otherwise, all the individuals belonging to a species in any given zoological province would leave their remains within the narrow stratum of deposit on which they had lived. But this happens only in exceptional cases; and hence we meet with fossil remains of species extending frequently through strata of such immense thickness as to prove, in conjunction with what is known of the rate at which those strata are formed, that vast changes in the relative distribution of sea and land must have occurred before they became extinct.

Bearing this fact in mind, it is necessary to avoid the very common error of taking for granted that the ancestors of animals living at the present time under a set of recognized conditions must have lived under similar conditions since the period at which they first appeared on the earth. The fossil remains of the older extinct forms, both of animals and plants, clearly show how different must have been the condition of the earth's surface when they peopled it. But we have only to look at the changes observable during much more recent periods, in order to be satisfied that species still in existence must have passed through repeated and critical alterations in the conditions by which they were surrounded; and in such cases we might naturally expect to find structural modifications to have taken place in a greater or less degree. A time will in all probability arrive when, by a further series of changes, these existing forms will in turn become scarcer and scarcer, and then finally disappear from the earth. The extinction of certain Struthious birds is well known to have been completed within a very recent period; and although in some examples human agency has been instrumental in producing this result, there is no reason to believe that in the case of the gigantic Struthious forms of New Zealand, or in that of the Great Awk of the Arctic regions, extinction has not been consequent on natural causes. But, supposing changes on the earth's surface and climates to have been moderate in extent and duration, it is evident that creatures may have survived

conditions which, if sufficiently protracted in their operation, would have proved fatal, and that they may have received a new vital impulse, as it were, from the relapse towards those conditions which were normal,—the alternate tendency towards extinction and re-establishment having been carried on through several repetitions of these changes, and resulting in an augmented or a diminished power to become permanent, as the digression from or recurrence to the normal state assumed the preponderance.

It is to Sir Charles Lyell that we are indebted for the first clear exposition of the relation subsisting between the geographical distribution of organized beings and the "inorganic changes" which are continually taking place over the globe. So long ago as the year 1832 this all-important subject was treated by him in the original edition of his 'Principles of Geology'—a work which constitutes at once the most compendious and the most perfect record of the great physical laws which have through all time modified the exterior of the globe. To Mr. Darwin's researches much is also due—authenticated examples of specific divergence having been collected and explained by him in a manner that leaves no doubt on the mind of the facts, although his final inferences are held to be "unproven" by some, and untenable by others.

Sir Charles Lyell remarks* that, however uniform may be the action of "inorganic causes," its effect on the organic world is far from being uniform in equal periods of time in different localities. There cannot be a doubt of the correctness of this view with regard to inorganic agencies operating on land, but there is good reason for supposing that when operating at sea their results are of a far more uniform nature in like periods; for, assuming, as we are warranted in doing, that over large equal areas of globe the amount of subterranean disturbance is similar during vastly extended periods, it follows, from the much greater area of sea as compared with land, that the effects would be diffused over a much wider space, and hence sudden changes in distribution of the sea-bed would be less frequent, whilst alterations in its depth would be much more slow in their production.

"We may fairly infer," says Sir Henry De la Beche†, "that the great mass of organic remains, like the accumulation of detritus amongst which such remains

* See Lyell's 'Principles of Geology.' London, 1853: p. 691 *et seq.*

† 'Researches in Theoretical Geology,' by Sir H. De la Beche, F.R.S., &c., 1834, p. 266.

occur, was accumulated in moderate depths around coasts, and either on or around shoals at no considerable depth below the surface of the sea." The same view has been held by all subsequent writers; and this may explain, in some measure, why it has been asserted that fossil species, which extend through the greatest thickness of a deposit or series of deposits, have in all probability also commanded the widest horizontal range,—the inference being based on the supposition that, during the vast periods of elevation or subsidence which rendered a change of position necessary, littoral species, in order to endure, must have traversed successively formed zones. If by horizontal range it is meant that such species must have lived along very extended coast-lines to admit of their surmounting the obstacles which occasionally prevented the maintenance of their normal depth, the view may be regarded as correct. Otherwise it would appear that the geological range has been confounded with the geographical, inasmuch as the measure of the horizontal area over which such a fossil species may be found constitutes but the sum of an indefinite number of geographical areas to each of which it was restricted for the time being. And hence, apart from other evidence, the greatest vertical as well as the greatest horizontal range of such a species, whilst attesting its duration, affords no proof of its wide geographical distribution at any given period.

In the case of fossil deposits formed at the bed of the deep sea, however, it may be fairly assumed that the horizontal range bears a much closer relation to the actual geographical distribution of a species at any given period of its history; for, although the sea-bed may be regarded as the reflex of the land, softened down somewhat by the deposits continuously accumulating on its surface, the very nature of the conditions present yields the creature living there a much greater chance of escape from hurtful influences than pertains to littoral species. Thus the latter, in event of elevation of a coast taking place, could descend in one direction only, to maintain their special bathymetrical zone; and should a shoal or reef skirt the shore, advance in that direction would be precluded. Therefore, unless the creature were capable of enduring a change of conditions incident on removal to a higher zone, even no further elevation of the coast-line took place, the result would be fatal to it.

In the case of deep-sea forms, excepting those located in circumscribed and isolated areas, the possibility of migration to a locality at which the conditions

were favourable to life would be vastly increased; that is to say, they would have two or more directions to select from, and accordingly the risk of extinction from inorganic causes would be materially lessened; the extension of the geographical range of a species, under these circumstances, being at the same time facilitated and expedited.

In the case of marine creatures, the necessity for migration from place to place in consequence of changes which render residence in particular localities unsupportable must, for these reasons, occur much less frequently. It is also reasonable to suppose that the tendency to extinction of marine as compared with terrestrial animals, from purely "inorganic causes," must be proportionately small, inasmuch as, the ratio of land and water on the globe being as 3 to 10, terrestrial animals must be more frequently checked in migrations which might save them from extinction, by the intervention of an element they are unfitted to encounter.

Again, human agency must operate to a much smaller extent in effecting the extermination of the smaller and lower forms of the animal kingdom in the ocean than it is known to have done in the case of creatures inhabiting circumscribed areas on land, since access to their haunts is, for the most part, impossible. And further, as there is good ground for believing that, although the deepest abysses of the ocean have their living occupants, the number of individuals is in all probability very large whilst the number of tribes is proportionally small, the tendency to extinction of certain tribes by furnishing sustenance to others becomes materially reduced.

Having thus cursorily and, I fear, very imperfectly detailed the chief causes which are concerned in determining the distribution and duration of marine species, I have yet to show how they bear on the question of life in the deeper abysses of the ocean. Before proceeding with this portion of my subject, however, it is necessary that I should describe, for the information of those who will, I trust, constitute a large proportion of my readers (namely, students of marine natural history and others who may have opportunities of taking soundings), the bathymetrical distribution of both the animal and vegetable creation, down to those depths which it has heretofore been customary to regard as azoic.

The late Professor Edward Forbes was the first to point out that the various species of marine animals and plants inhabit distinct successive zones or belts, commencing with high-water mark and extending downwards, as he himself

defines them, "to the deepest abysses from which living beings have been extracted." There are four of these zones in the European seas, each of which is marked and may at once be recognized by typical organisms or groups of organisms peculiar to it and to it only. Some organisms, however, are common to all the zones, whilst others are only common to two or three.

The first or littoral zone is that which extends between tide-marks, whether the rise and fall be one foot or fifty.

The second or Laminarian zone extends from low tide-mark to a depth of about 15 fathoms, and forms the great centre of sea-weeds, "fishes, mollusks, Crustaceans, and Invertebrata of all classes, remarkable for the brightness and the variegation of the patterns of their colouring."

The third or Coralline zone reaches down to a depth of about 30 fathoms below the limit of the Laminarian zone. Here both vertebrate and invertebrate animals are abundant, but plants become scarce.

The fourth or deepest, namely, the deep-coral zone, extends towards that abyss where, to repeat Professor Forbes's words, "life is either extinguished or exhibits but a few sparks to mark its lingering presence." It may be said to reach down to a depth of from 300 to 550 fathoms in different latitudes, although, according to Forbes's observations, its limit falls short of either of these estimates*.

It will be observed that the vertical limits of each of these zones increases with the depth; so that whilst the upper has a depth of only a few feet, the lowest ranges from 100 to 300. "Specific animal forms," writes Mr. Austen, "decrease rapidly; and just as the sub-aërial zones of vegetation present us at last, as we ascend, with only such forms as lichens, so at depths of from 70 to 100 fathoms we have the obscure Nullipores as the extreme forms of marine vegetation"†.

I shall hereafter show that, at depths vastly exceeding those above alluded to, animal life is abundantly represented; and, as already stated, although the crowning evidence still remains to be elicited in the case of the Foraminifera and Polycystina (namely, vital movements after being brought up from the sea-bed), such evidence has already been elicited in the instance of creatures of a far higher order, namely, radiate animals—facts being forthcoming to prove that

* See 'The Natural History of the European Seas,' by the late Professor Edward Forbes, p. 24 *et seq.*

† Ibid. p. 189.

their normal habitation is in the deeper abysses of the ocean, whilst presumptive evidence of the vitality of the Foraminifera with which they are associated is afforded by the remains of these having been detected by me in the digestive cavities of the radiate creatures in question.

Assuming these facts then for the present, we have to modify to a considerable extent the usually received views regarding distribution and duration of species, to which attention has already been drawn.

Since we know that similar climates and conditions of the earth's surface do not necessarily involve the presence of the same kinds of organized beings, and, on the other hand, that the association of similar forms does not involve the existence of a similar climate, we are justified in supposing that animals of the same species (that is to say, originating from one specific progenitor), now living under widely different conditions as to climate, have gradually become habituated to the transition from one set of conditions to the other, during the lapse of extended periods in which alterations in the distribution of sea and land, of sufficient magnitude to have produced these climatal differences, have taken place.

But it appears to me that this inference is warranted, whether we accept the doctrine of single specific centres or that of the transmutation of species, since it is conformable with all that is known of the duration of species to believe that the period requisite to effect marked modifications in their characters is brief, in comparison with that which is included between their first appearance on earth and their final disappearance from it, and, hence, that the duration of any given form may be regarded as often extending beyond the period occupied in any single change in the distribution of land and sea. For it is evidently unphilosophical to suppose that a species, once fairly established, should disappear from the face of the earth before it had passed through that specific life which is as essentially a law of nature as the life of the individual—and tantamount to an assertion that creation is without a purpose, and under the influence of accidental agencies.

Whatever views may be entertained regarding the origin of species, it is universally admitted that they are associated together in distinct groups, each of which is typical of the zoological province in which it occurs, in the same manner that certain species are typical of each group—the same group and the

same species never being repeated either in space or time, and the same species never appearing in two or more provinces, except as an emigrant from its genetic centre. By what laws the adaptation of particular regions for particular species is determined we have at present no means of ascertaining, inasmuch as the existence of similar climates neither involves the presence of similar species, nor is the presence of similar species necessarily associated with the existence of similar climates.

But whilst the distribution of living animals and plants has already been defined throughout the entire terrestrial portion of the globe with a close approach to accuracy, our knowledge of the distribution of the inhabitants of the ocean has been almost entirely restricted to coast-lines, and even as regards these we have no systematic information beyond European seas. The great zoological provinces of the open ocean may therefore be regarded as unexplored, save in the case of a limited number of free-floating organisms; and, as a natural consequence of the antibiotic view respecting its deeper abysses, the entire submarine provinces of life, vast and varied as they must be if life be there present at all, remain as yet a *terra incognita*.

In our endeavours to trace the distribution of the lower microscopic forms of animal and vegetable life, the difficulties are still further enhanced owing to the greatly increased liability to diffusion by accidental causes, and a large proportion of the entire series having thus become common to every portion of the globe. Nor is this world-wide dispersion confined to recent species; for, as shown by Ehrenberg, it extends to many fossil forms. Amongst the Foraminifera, living species still abound in our seas which flourished in the ancient seas of the Mesozoic period, long before any of the now living species of the higher orders of the animal kingdom had as yet made their appearance on earth. The same universality of distribution is to be observed amongst the Polycystina, and, on the vegetable side, amongst the Diatomaceæ and Desmideaceæ, although in the fossil condition the two former have not hitherto been detected so far back in time, and the latter are altogether unknown*. When the extremely minute

* It has been customary to regard certain minute spinous bodies in the Cretaceous flints as sporangial cells of Desmidiaceæ. The Rev. J. B. Reade was the first to draw attention to these bodies, in a paper published in 'The Annals of Natural History' for 1838. Subsequently they were detected by Mr. Deane in the substance of the Chalk itself, and were shrewdly surmised by him to be of animal origin (Trans. Microscop. Soc. 1849, vol. ii.). In 1851, and again in 1857, the organisms referred to

and fragile nature of the Desmidiaceæ is taken into consideration, this is hardly to be wondered at; but as regards the Polycystina and Diatomaceæ, it is far from improbable that we only fail to detect them owing to the presence, in both fresh and salt water, of substances which unite with and thus obliterate all trace of their siliceous structures. Should this surmise be correct, fossil representatives of these organisms may yet be found whensoever an ancient sea, lake, or river-bed shall present itself which has been so suddenly upheaved by subterranean force as to have been denuded of its waters before chemical combination could take place*. But, even without this additional fact, we have ample proof that the

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were detected by me in the material obtained from the stomachs of *Salpæ* in the Indian Ocean and mid-Atlantic; and although at the time regarded by me as true pelagic representatives of the Desmidiaceæ and Diatomaceæ, more recent observation has convinced me that, in the case of the former, the resemblance is one merely of form and not of structure, the Xanthidium-like bodies being distinctly of animal origin.

* Since the above observation was put in type, a short notice has appeared in the 'Geologist' for June 1862, which, in a great measure, confirms this surmise. It is there stated that, in the "hornstone nodules of the *Devonian* and *Silurian* rocks of New York, organisms similar to, and probably identical with, those which occur in the Cretaceous flints and the Chalk itself, have been detected by Professor Dana and Dr. M. C. White." As the importance of this fact is in reality far greater than at first sight appears, I subjoin an extract from a paper, detailing my reasons for doubting the vegetable origin of the organisms in question, published by me in the 'Quarterly Journal of Microscopical Science' for October 1860, "On the Siliceous Organisms found in the Digestive Cavities of the Salpæ":—

"The history of the fossil *Xanthidia* of the Cretaceous flint nodules has hitherto been beset with a most perplexing difficulty. Apart from the much-vexed question as to the manner in which the siliceous element of the nodules became aggregated into masses, so as to enshroud these structures, the occurrence of organisms, held to be strictly inhabitants of fresh water, in deposits of unquestionable marine formation, presented an ample field for discussion and conjecture. The Desmidiaceæ, of which family the Xanthidia constitute the sporangia, are thus described by Mr. Ralfs: 'All the family are inhabitants of fresh water. Mr. Thwaites, indeed, has gathered two or three species in water slightly brackish; but the same species are also found in localities remote from the sea. Certain marine objects that have been classed with the Desmidieæ have the internal matter of a brown colour, but these belong to the Diatomaceæ.'—*Ralfs, 'British Desmidieæ,'* Introd. p. 2.

"In order, therefore, to account for their occurrence amongst purely marine deposits, it was deemed necessary to assume that they had been washed down by rivers or floods, or transported by winds from the land to the sea, where, after gradually subsiding, they became incorporated with the siliceous material in which they were found imbedded. The tough, semi-horny texture of their outer covering, and well-known power of withstanding extreme climatic changes, seemed to favour this idea of their indestructibility, even under conditions so opposed to those in which they originally lived. But the explanation was, at best, unsatisfactory.

lower the organism in the scale of being, the greater is its numerical intensity, the more universal its distribution, and the longer its duration in time,—one and all of these characteristics being dependent, not on increase of power to withstand destructive influences, but on decrease of sensibility to them.

It is well known that the geographical distribution of terrestrial life is mainly dependent on climate, that is to say, on the several agencies which modify the condition of the atmosphere and the earth's surface in different latitudes. These agencies are temperature, elevation, amount of moisture, carbonic acid and accidental gases in the atmosphere, configuration of surface, and light. If we turn to the ocean, we find that similar or at least equivalent agencies determine the distribution of the creatures that inhabit it. The following Table will serve to illustrate the relation of these agencies in the two cases, their aggregate values being empirically estimated at 1000:—

Land.		*Sea.*	
Temperature of air	400	Temperature of water	350
Elevation above sea-level Rarefaction of air	200	Aëration of ditto	300
Amount of moisture in ditto	100	Depth below surface Amount of pressure	100
Carbonic-acid gas in ditto Ammoniacal and accidental gases in ditto	50	Carbonic acid in water Saline constituents in ditto	150
Configuration and composition of surface	150	Configuration and composition of bottom	50
Light	100	Amount of light	50
Total..	1000	Total..	1000

"The discovery of two well-marked varieties of *Xanthidia*, in a recent state, amongst the alimentary contents of the *Salpæ*, was therefore fraught with no slight interest. From the condition of their endochrome it is certain they had but recently been inclosed in the cavities of these creatures; and from the situation in which they were discovered, it is equally certain that they could not have been derived from freshwater sources by any of the agencies above referred to. But whether or not these bodies are the sporangia of genuine pelagic *Desmidiaceæ*, they certainly exhibit an identity of appearance and structure with the fossil forms, too striking to admit of question. The probability, however, of their being true pelagic representatives of this family is greatly enhanced by the occurrence, in the same material, of bodies closely resembling the *Closteria*. These have only been met with sparingly, and it has been impossible, therefore, to determine their nature with certainty. But the strongest evidence in favour of their identity with the fossil *Xanthidia* is derived from their association, in the recent state, with other organisms, such as *Diatomaceæ* and *Foraminifera*, whose fossil remains, in like manner, occur associated with them in the flints. The question as to their being true sporangia of *Desmidiaceæ* becomes, therefore, of secondary importance."

Although the temperature of the ocean is much more equable than that of the atmosphere, there is good reason to believe that its waters are susceptible of climatic changes of a very important nature as regards their effects on the distribution of life. No doubt these changes are more frequent and less lasting near the surface, and hence operate more markedly on the creatures that inhabit the superficial zones; but it must be borne in mind that the very nature of the conditions, dependent as they are principally on the reciprocal action of the atmosphere and water, presupposes a different set of conditions as the depth increases, and, hence, that a limit is speedily attained, beyond which the sudden advance of creatures living above or below becomes at once injurious to them. It is only when we regard the comparatively insignificant stratum of water to which animal existence has heretofore been supposed to be circumscribed, that the capacity of the ocean for the maintenance of life falls short of that which we are in the habit of ascribing to the atmosphere; and the moment it is recognized as a fact that animal life, instead of being confined to the few hundred superficial fathoms, reaches down into the deeper abysses, it becomes evident that the vertical limits above and below the sea-level are in reality almost coequal.

Although any attempt to construct a bathymetrical plan of the deeper zoological zones of the ocean would at present be premature, the data in our possession are nevertheless sufficient to warrant the inference that, where a few living forms have been detected, numerous others exist; and, accordingly, the construction of such a plan may be regarded merely as a question of time and scientific research. There may be blank areas on the sea-bed, as there are unquestionably blank and uninhabitable areas of land; but, again, assuming that the conditions are not of a nature to render life impossible, we are warranted in taking for granted that these areas are no greater in the one case than in the other. "The history of our own seas and of all seas," observes Mr. Godwin-Austen, "teaches us that there is a law of proportion in the classes and orders of the living things that dwell there, and that the presence of one form is safe ground of inference as to the co-existence of countless others"*. Higher authority than this we could not have; for, although the doctrine thus enunciated bears reference to the distribution of life apart from that of the deep sea, it must be admitted that the same general application of the laws of nature, for which Mr. Austen is so

* 'Natural History of the European Seas,' p. 247.

staunch an advocate, is admissible in the present instance the moment the existence of one living form in the depths of the ocean is incontrovertibly proved.

Although temperature is the most important element in determining the climate of a region, its independent influence (that is to say, the temperature of a locality as due to its geographical position only) is subject to great modification from collateral causes—namely, the degree of elevation above the sea-level, the amount of humidity present in the atmosphere, the prevailing winds, and the surface-configuration. These all act reciprocally on each other, and in certain cases produce such alterations in the climate within the same area as would result from a complete change of geographical situation. Thus, at a given height on the mountain-ranges of equatorial countries we find a region of perpetual congelation, and in descending from that elevation towards the sea-level there occurs every variety of temperature, from arctic cold to tropical heat; the various zones being distinctly marked by the character of the vegetation they are adapted to support.

If we turn to the ocean, we find its climates are dependent, in like manner, on causes which modify its temperature, namely, the temperature of the superincumbent air, the prevailing currents, and, to a limited extent, the configuration of its bed,—the currents, like the winds on land, serving to equalize the heat and prevent stagnation; whilst, in shallow waters, the nature of the bottom serves to modify the force and direction of the currents, and, both in shallow and in the deeper portions, it exercises a powerful influence in determining the kind and the distribution of the creatures that dwell upon it.

It is well known that in every latitude, commencing from the confines of that portion of the polar area within which the temperature is said never to rise above freezing-point* and extending to the equator, there exists a belt of atmosphere of varying thickness, which marks the oscillation of the line of perpetual congelation during summer and winter. It is obvious that the upper boundary of

* It has been customary to assume that at about the 75th degree of latitude the line of perpetual congelation is coincident with the sea-level; but, according to Sir John Richardson, this does not accord with observation in the Northern Hemisphere, there being "no Arctic district to which man has as yet penetrated in which there is a permanent covering of snow through any wide extent of low country."—See 'Arctic Searching Expedition,' by Sir J. Richardson, C.B., F.R.S. London, 1851: vol. ii. p. 213.

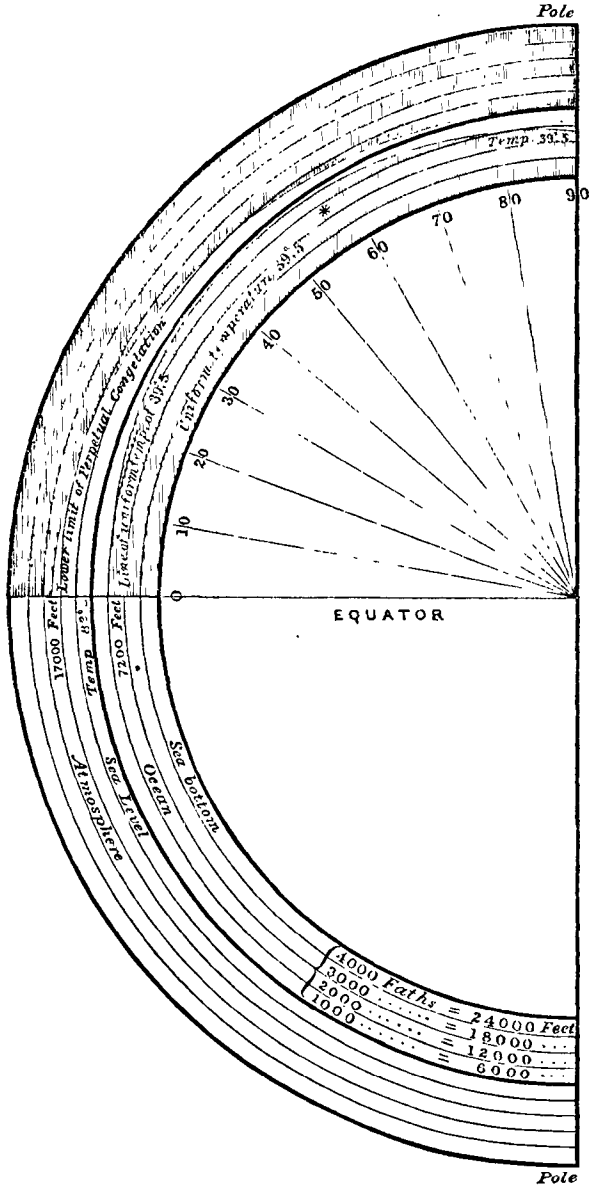
this belt, if traced along any given meridian, would be coincident with the sea-level in the first of these positions, whilst it would attain its maximum elevation above the sea-level in the last; or, taking the mean of such oscillation, that an arc of a circle might be described somewhat nearer to the level of the sea than the upper margin of the belt, which would denote the mean annual altitude of the snow-line.

Inasmuch as the temperatures of the ocean and atmosphere are in a great measure mutually dependent on each other, and both derive their heat from the same sources, we might naturally expect to find a line of uniform temperature in the sea which would bear some evident relation to that in the atmosphere; and such is the case, although the space above and below these respective boundary-lines is subject to widely different laws. Thus, in the ocean we meet with an isothermal curve, which attains its maximum depth below the surface at the equator, and is coincident with the sea-level (that is to say, rises to the surface) in lat. 56° 62′, dipping down again as it advances from that point to the pole. Although this isothermal curve is liable to slight oscillation from similar causes that bring about the oscillation of the aërial belt, the variation is so small as to be hardly perceptible; and accordingly, a series of two larger and two smaller arcs, described along any given meridian, will represent the line of uniform temperature of the sea with sufficient accuracy for present purposes. But whilst the temperature of the atmosphere beyond the line of perpetual congelation goes on gradually decreasing*, that of the water below the isothermal line remains constant to the bottom. Were it not for the operation of the law on which the latter phenomenon depends, the entire ocean would long since have become solidified and both sea and land rendered unfit for the habitation of living organisms. Unlike other bodies which expand and become lighter with every rise in temperature, water attains its maximum density, not under the lowest degree of cold, but at 39°·5 Fahr.; and consequently, as soon as the superficial layer of sea is cooled down towards this degree, it descends and allows a fresh portion to ascend and be in turn cooled. This process is continued until the whole upper stratum is reduced in temperature to 39°·5, when, instead of contracting further, it begins to expand and get lighter than the water beneath, floats on it, becomes

* According to M. Fourier, the temperature of the ethereal regions has been estimated at —50° F., whilst M. Pouillet estimates it at —220° Fahr. (Somerville's 'Physical Geography,' vol. ii. p. 33.)

further cooled down, and at $28\frac{1}{2}°$* is converted into ice. In this state, having arrived at its maximum lightness, its position remains unchanged; and being a bad conductor of heat, the circulation between the superficial and lower strata ceases and thereby prevents the congelation of the entire body of water, which would take place did the density increase indefinitely with the decrease of temperature so as to permit of congelation commencing from the bottom instead of the surface of the sea.

Thus, under the operation of an apparently exceptional law, the equilibrium of the oceanic circulation is maintained; for whilst at the equator the mean temperature of the surface-layer of water, which is 82°, gradually decreases until at a depth of 1200 fathoms it becomes stationary at 39°·5 Fahr., and retains that temperature to the bottom, within the polar regions, and extending to lat. 56° 25′ in either hemisphere, the temperature increases from the surface downwards to the isothermal line, beyond which it remains uniform as in the former case. Hence in lat. 56° 25′, the temperature is uniform the whole way from the surface to the bottom, and, as has been found by observation, about lat. 70° the isothermal line occurs at 750 fathoms below the surface. The annexed diagram will give a general



* The freezing-point of salt water.

idea of these two isothermal curves, and also of the temperature of the water from surface to bottom, in the locality at which the Star-fishes were captured,—a most important fact, to which I shall have to refer particularly hereafter.

Although a certain amount of heat is constantly being given off from the interior of the earth, its quantity is so small as to exercise no perceptible influence on climate. On the other hand, the quantity of heat annually received from the sun, and upon which the temperature of the earth's surface may be said entirely to depend, is so great that, were an equal amount not radiated into space, the temperature would very speedily become insupportable. The quantities given off from the first of these sources, and received through the last, have been computed by M. Peltiers and M. Elie de Beaumont with reference to their capability for dissolving a certain bulk of ice,—it being computed that the quantity of central heat which reaches the surface of the earth in the course of a year would suffice to melt a layer of ice a quarter of an inch in thickness, covering the entire globe, whereas the quantity of heat received directly from the sun in the course of a single year would suffice, in a like period, to melt a layer of ice 46 feet in thickness, covering the same area. But, notwithstanding the amount of solar heat thus imparted to the earth, its influence does not extend deeper under the surface than from 60 to 90 feet; whilst below this point there is a regular increase of temperature, arising from the earth's central heat, amounting to 1° for every 55 feet of descent.

It follows that, at any given depth of sea-bottom, the heat emanating from the earth's centre is the same as would occur at the same depth of solid crust, but that, owing to the rapidity with which the temperature communicated is diffused through the entire mass, all accumulation of heat is prevented. Hence, although the line of uniform temperature in the ocean is unquestionably modified to a certain extent by the heat received from below, its depth below the surface is entirely regulated by the amount of solar heat absorbed, coupled with the amount of radiation, incident on the degree of latitude. In shallow seas or along coast-lines, where the disturbing action of tides, currents, and inequalities of the bottom is felt, as a matter of course, the isothermal line vanishes, and the temperature of the various vertical zones of water is determined by a new set of conditions.

For these reasons, whilst temperature may justly be regarded as the most important element in regulating the distribution of life within the bathymetrical limits hitherto insisted on as extreme, it becomes highly probable that, in those profounder abysses, extending from a quarter of a mile below the surface to depths yet unfathomed by the sounding-machine, this uniformity constitutes the pre-eminent condition of animal existence, and that a number of creatures formed to live under it will yet be found equally distributed throughout the vast area of the sea-bed.

It has long since been ascertained that the number of types, as also of genera and species, of the animal and vegetable kingdoms materially diminish as we advance from equatorial to polar regions; and hence this decrease cannot be regarded otherwise than as indicative of dependence on reduction of temperature. Until a little more is known of the deep-sea fauna, it would be injudicious to speculate on the relative numerical proportion of its members in different latitudes. But we are warranted in assuming, even from the scanty data already at our command, when taken in conjunction with the established uniformity of climate prevalent through the length and breadth of the deep-sea bed, that no such marked variation exists as that just referred to in the case of the terrestrial and the superficial marine fauna. And further, if it be legitimate to estimate the profusion of deep-sea forms generally by the number of individuals belonging to the same species which were brought up from a single spot of the sea-bed, there is every reason to believe that it falls short in no degree of that observable amongst species frequenting the superficial zones.

It is a very significant fact, and one the importance of which was fully appreciated by Edward Forbes and Professor Löven, that the greatest profusion of typical Invertebrata is to be met with, not in the superficial, but in the deeper zones of the Arctic and Boreal provinces, and, moreover, that the downward range of the four bathymetrical zones is much more extended than in the Celtic or Lusitanian provinces. Want of time and opportunity unfortunately prevented me from carrying out my intended series of observations on the bathymetrical range of the Greenland Invertebrata; and, as noted in my diary, my dredgings at Goodhaab were altogether confined to the fiords near the anchorage, where the depth of water did not exceed 200 fathoms. But even this limited experience left no doubt on my mind that the abundance of some of the forms met

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with falls far short of that which occurs throughout the next 100 or 200 fathoms, inasmuch as the number of individuals regularly increased down to the greatest depth reached by the dredge. On the other hand, there was a distinct decrease both of animal and vegetable life in that stratum of surface-water which corresponds to the littoral and laminarian zones of the southern provinces. In the shallow channels which, here and there, form the communication between adjoining fiords, the various species were scantily represented; and from the immense masses of decayed Algæ interspersed amongst those in the full vigour of Greenland summer growth, it is evident that the alternation of seasons, either directly by change of temperature or indirectly by the production of so much fresh water, must exercise a more hurtful effect than it does where the climate is milder and more equable. In the fiords themselves, both of Labrador and Greenland, where the marginal depth ranges at once from 10 to 20 fathoms, the growth of Algæ is more or less absent near the surface, and only commences at the point at which in other latitudes it usually ceases.

The subjoined is the general result of my few dredgings at Goodhaab:—

From 50 *to* 100 *fathoms.*

CRUSTACEA.

Hyas arenaria.

MOLLUSCA.

Hiatella arctica.
Cardium Grœnlandicum.
Pecten islandicum.
—— pectinatum.
Mytilus edulis.
Trophon Fabricii.
—— Grunneri.
Margarita striata.
Volutomitra Grœnlandica.
Astarte elliptica.

ANNELIDA.

Pectinaria.
Spio.
Cirratulus.
Syllis.
Terebella.

COTTIDÆ.

Cottus glacialis (Rich.).

From 100 *to* 200 *fathoms.*

CRUSTACEA.

Hippolyte polaris.
Gammarus arcticus.
Caprella linearis (on Algæ).

MOLLUSCA.

Acmea testudinalis.
Chiton marmoreus.
Natica Grœnlandica.
Lima Subauriculata (East Coast in sounding).

TUNICATA.

Boltenia picta, n. s.?

ECHINODERMATA.

Echinus sphæra.
—— neglecta.
Ophiocoma bellis.
—— granulata.
—— Goodsiri.
Ophiura texturata.
Solaster papposa.

ANNELIDA.

Serpula contortuplicata.
Terebella (several species).
Spirorbis communis.

Connecting the increased downward range of the organisms here named with the prevailing temperature at the surface and the subsidence proved to have taken place along the western coast of Greenland, it appears difficult to regard them otherwise than as cause and effect, and as indicating the first step towards that tolerance of extreme conditions which we have hitherto been taught to consider impossible.

Again, according to Mr. M'Andrew, there is a distinct tendency of northern forms to inhabit deeper zones as they approach the equator,—a very remarkable example having been adduced by that gentleman in the distribution of the Testacea at Mogadore, on the West Coast of Africa. Thus, out of 110 species, about one-half of which range north as far as our own coasts, 88 were found at depths not exceeding 30 fathoms, and amongst these were all the characteristic African and Lusitanian species; whilst out of 22 species obtained at depths varying from 35 to 50 fathoms, all but six were well-known British shells*.

Excessive cold is undoubtedly the chief antibiotic of the polar and sub-arctic regions. The thick belt of ice which hangs about the shores of Greenland and Labrador for at least eight months out of every twelve, and which, on its breaking up, clears the rock-surfaces of a great portion of their fixed animal and vegetable forms, fully accounts for the barren aspect of the Littoral and Laminarian zones, except in the shallow channels above alluded to, and along projecting spits where the inclination is so gradual as to prevent the close approach of the heavy ice. Both near Goodhaab and Julianshaab, and also on the Labrador shores, the entire absence of every trace of animal or vegetable structure along the more exposed tracts was very remarkable; and, in addition to this, the rocks themselves were worn down and polished to a much greater extent than could have been effected by wave-action or weathering alone. There was no indication, however, of the increase of littoral animals or plants having been permanently arrested, or of actual death having ensued, from any degree of cold short of protracted congelation. The healthy condition of the fixed organisms obtained from a depth in the fiords just below the limit of annual congelation, and the absence of the disintegrated masses of Algæ which must have been observable had they been involved in it, attest this fact; and, as already stated, a very remarkable

* See 'Natural History of the European Seas,' p. 227.

example of the endurance of cold was afforded by the Medusidæ and Beroïdæ, which were seen, during calm weather in the fiords, disporting themselves in the closest proximity to the ice-masses. Nevertheless, it is evident that there is a bound to this endurance for each kind of organism, inasmuch as a number of dead specimens of the beautiful little *Spirialis* were brought up, off Cape Farewell, from a depth of 1177 fathoms, the soft parts and fragile shells of which were in such a perfect state of preservation as to render it evident they had perished amongst the ice and subsided to the bottom after death; whilst the extremely rare appearance of *Spirialis* and the more common Gymnosomatous Pteropods at the surface, during the entire period of our cruise in the Greenland seas, clearly pointed to the abnormal influences that had there presented themselves.

The effect of extreme cold, or indeed of any degree of cold greatly in excess of that which is habitually borne by animals and plants inhabiting different latitudes, first retards growth, then restricts it, and, if sufficiently protracted, causes death. The same may be said regarding the effects of extreme heat; but there is good ground for the belief that creatures indigenous to a cold region can endure with impunity much greater vicissitudes of temperature than those indigenous to a warm region; that is to say, a creature living in the sea where its temperature is 40° Fahr. could sustain an increase of 40° with greater safety than a creature living where the temperature is 80° could sustain a decrease of a like extent. Or, to put another hypothetical case, if an arctic and a tropical species were respectively placed under the conditions most congenial to them, and then subjected, the one to a great and sudden increase, the other to as great and sudden a decrease of temperature, the arctic species would, in all probability, suffer the least.

But the most important point in favour of the arctic over the tropical species remains to be noticed, and it is as follows:—Assuming that no arctic species, under any circumstances, is subject to a wider range of temperature than that between the freezing-point of salt water (namely, 28½° Fahr.) and the mean temperature of the ocean (namely, 39°·5), it is obvious that, if accidentally transported to any distant region, it can at all times command the latter temperature by migration to a deeper zone; and accordingly, if we put pressure out of the question (as I shall immediately endeavour to show we can do without infringing a single condition of marine existence), there is no bathymetrical

limit to animal life in the ocean beyond that depending on the presence of the necessary food. But in the event of a tropical species being accidentally transported, say to the Boreal province, it follows that if it survive at all, it can only do so by accommodating itself to a change of temperature very nearly three times as great as in the former example. These are undoubtedly extreme cases, but they are nevertheless possible ones; and I desire to draw attention to the very remarkable inference that may be deduced from them, namely, that whereas migration from the equatorial towards the polar regions is beset with extraordinary difficulty, and hence tends towards that concentration of surface-life which is known to occur in the former of these, migration from the polar regions towards the equatorial presents hardly any obstacle. Why then, it will be demanded, do we not find arctic forms in tropical waters? Because, from the very nature of the conditions, the migration must take place along the deep homothermal sea—that great highway extending from pole to pole, which is for ever closed to human gaze, but may, nevertheless, be penetrated by human intelligence*.

If the arguments in support of what has been termed the antibiotic view be carefully scrutinized, they will be found to rest almost exclusively on the negative evidence afforded by the enormous pressure present at the bottom of the ocean. For, although the decrease of light, of aëration, and of the ordinary sources of food was regarded as contra-indicative of "any kind of life analogous to that with which we are acquainted," apart from the operation of pressure, there is nothing in these conditions to render life impossible. It had not been taken into consideration that the more recently devised appliances for bringing up the material from the sea-bed were singularly unfitted to secure any living creature larger or more specialized in structure than the Rhizopod, even if present, and, hence, that the mere circumstance of failure to capture creatures of higher type afforded no proof whatever of their non-existence; whilst by a retrogressive kind of reasoning it was maintained that the Rhizopod could not

* To Sir James Ross is due the merit of having been the first to catch a glimpse of the relation subsisting between the belt of uniform temperature, so admirably explored by him in the Antarctic seas, and the migration of deep-sea species. For, although he based his inferences, as already stated, on observations made during the Voyage of Discovery to Baffin's Bay in 1819, and which were regarded by naturalists (without a single exception, as far as I am aware) as unsupported by sufficient evidence, his faith in those observations was as natural as the incredulity of the scientific world was illiberal.

live at extreme depths, simply because it exhibits no trace of active vitality after being dragged from a normal to an abnormal element.

Again, false analogies were advanced to show what would be the effect of the stupendous pressure known to prevail at the bottom of the ocean on creatures constituted to exist under a totally different series of conditions. Thus, the collapse of the air-bladder in some fishes, the disembowelment of others, the inconvenience experienced by persons when carried down only a few fathoms in the diving-bell, the long and arduous training undergone by the pearl-fisher, the hackneyed experiments on submerged logs of wood and legs of mutton, and, lastly, the fact that limestone could be fused under the pressure present without parting with its carbonic acid, have one and all been more or less emphatically dwelt on and handed down from writer to writer, until, like a troubled dream which the mind finds it difficult to shake off, a fictitious belief in the analogy of the cases was engendered.

To air-breathing terrestrial animals the diminution of pressure accompanying increase of elevation above the sea-level stands in the same relation as the increase of pressure attendant on augmented depth does to water-breathing creatures in the ocean. Every one is aware that, at the level of the sea, the pressure of the atmospheric column upon every square inch of surface is equal to $14\frac{1}{2}$ lbs., and, hence, that the pressure distributed over the body of an average-sized man amounts to about 33,600 lbs., or nearly 15 tons. Now, since at an elevation of 18,480 feet the weight of the superincumbent column is reduced one-half, according to the law of the expansion of gases, these $14\frac{1}{2}$ lbs. would be reduced to $7\frac{1}{4}$—a degree of rarefication which is constantly undergone by travellers without danger and but a very moderate degree of inconvenience if gradually encountered, and not greatly in excess of that present in the great mountain-ranges of tropical America and Asia, where we meet with flourishing cities and villages, surrounded by abundant cultivation*. It is obvious, therefore, that the human frame, endowed as it is with an unparalleled degree of complexity and susceptibility to external conditions, may nevertheless thrive for any length of time in an atmosphere so rarefied that the too abrupt transition to it from the sea-level would be attended with serious if not fatal consequences.

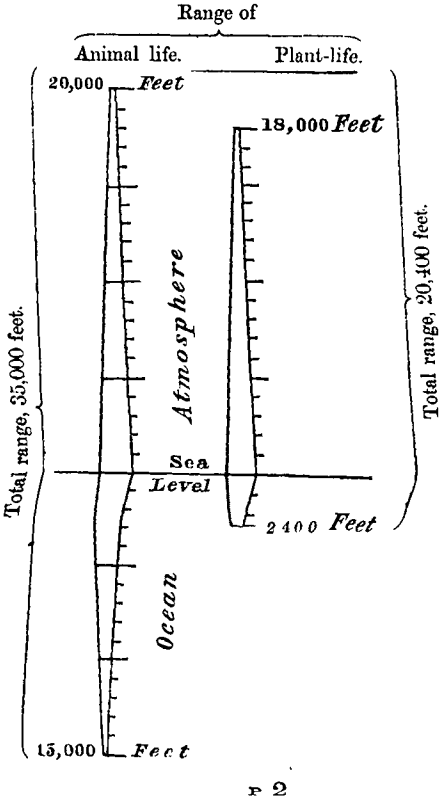
* Quito is situated at an elevation of 10,000 ft. above the sea-level. The Potosi mines, on the table-land of Bolivia, occur at 16,000 ft. Some passes in the Himalayah have an elevation of 20,000 ft.

In the Condor of the Andes we have a notable example of the power possessed by the Vultures to accommodate themselves to rapid changes of atmospheric pressure. Humboldt describes this bird as soaring for protracted periods at an elevation of 18,000 feet; and it is known to live and breed at from 10,000 to 15,000 feet. I have myself seen the common Eagle of the Himalayas soaring for hours at very little short of the same height. Fishes abound in mountain-lakes up to 13,000 feet; whilst there is no elevation, short of the limit of perpetual snow, at which the microscopic forms both of the animal and vegetable kingdoms do not habitually live; and it is highly probable that, in the latter case, it is the diminution of temperature, and not the increase of rarefaction of the atmosphere, which determines their ascending limit.

Again, plants flourish at very great heights. In Chili and Peru, wheat grows abundantly up to 13,000 feet; in Mexico, the limit of trees and shrubs is said to be 13,000 feet also; whilst in the Himalayas, as recorded by Captain Gerard, the *Genista*, a kind of broom, is to be met with at from 17,000 to 18,000 feet above the level of the sea.

Assuming then 18,000 feet to be the extreme vertical limit of plant-life above the sea-level, and 400 fathoms, or 2400 feet, as its extreme limit below, and, at a moderate estimate, 2500 fathoms, or 15,000 feet, as the limit in depth of animal existence in the ocean, and 20,000 feet as the extreme altitude which any animal can encounter above the sea-level, we obtain a total vertical range for plants of 20,400 feet, and for animals of 35,000 feet. Hence the ratios are as follows:—

Total vertical range, above and below *sea-level*, of plants as compared with animals, nearly .	5 to 7
Vertical range of terrestrial as compared with marine animals	4 to 3
Vertical range of terrestrial as compared with marine plants	15 to 2
Vertical range of terrestrial plants, as compared with terrestrial animals	9 to 10
Vertical range of oceanic plants, as compared with oceanic animals, about	1 to 6



It has been pointed out, at a previous page, that temperature is the most important as well as the most uniformly operating condition in the distribution of terrestrial animal life, and, moreover, that it exerts an equivalent influence on marine life. When, however, we estimate its effects on the bathymetrical distribution of animals and plants in the ocean, we find them to be extremely unequal; for, whereas marine organisms are now known to exist at a depth of at least 15,000 feet below the surface, no vegetable structures with which we are acquainted have been met with in a living state lower down than 2400 feet. But, although it would be premature, with our present knowledge of the deep-sea bed, to assert that this limit may not be considerably exceeded, there is every reason to believe that, beyond that depth, a boundary is rapidly attained at which a condition absolutely essential to plant-life in the ocean fails, and hence renders its downward extension impossible. That condition is light.

The two next conditions are elevation above and below the sea-level. A small representative value is assigned to these, because, although associated with the hitherto subtle and unexplained influences which at times determine the appearance of certain creatures in certain strata of the atmosphere, and also of certain creatures in certain bathymetrical zones of the ocean, there is no ground for the supposition that, *per se*, they exercise any effect of the kind. What these influences may be, there are at present no data whereupon to form a conjecture, since they have hitherto been recognized only by their results. It is clear, however, that they are not due to temperature, since the same temperature at different periods does not produce similar results on the organisms in question. In like manner, they are not attributable to rarefaction or pressure, since under a similar amount of pressure or rarefaction the same phenomena do not necessarily occur. It is possible, and even probable, as regards the ocean, that they may be in some way connected with the amount of light present, inasmuch as light exercises a marked influence on the appearance and disappearance of life near the surface of the ocean, and of certain animal forms in given strata of the atmosphere. But even here we meet with the same inconstancy of action as in the former cases, as shall be shown hereafter—several new and highly interesting facts tending to show that, whilst a certain quantity of light is absolutely indispensable to the growth and colour of certain plants, it is

by no means essential either to the growth or to the colour of the animal forms of the ocean.

It is obvious that rarefaction of the air, in the main, implies elevation above the sea, and attendant decrease of temperature; but it also involves something more, since we find certain birds, as for example, the Tropic-bird (*Phaëton*), almost invariably flying at a great elevation, even in the calmest weather. Here temperature can exert no influence; for, were the object to be attained a reduction of temperature, the bird would naturally frequent cooler latitudes, further removed from the equator than those it is usually found in. From the structure of the head and beak, the "Tropic-bird" is clearly an animal-feeder, preying, like most birds that frequent the open ocean, on minute Animalcules, Crustaceans, and Molluscoids. The selection of great heights, therefore, cannot be held to be due to the search for necessary food, but to some instinctive preference for a less dense atmosphere. In like manner, the Govinda Kite, both in the mountains and plains of India, remains, for many hours daily, at very great elevations in the atmosphere. The search for food cannot be the incentive in this instance, since these birds soar as often after their meal as before it, and frequently under circumstances which render it but too palpable that food is in superabundance.

Some idea may be formed of the vastness of the pressure prevalent at great depths from the fact (which may be readily proved by recourse to a few figures) that at a depth of a mile it amounts to 2640 lbs., or 160 atmospheres, on every square inch; whilst at 4000 fathoms, which is equivalent to about $4\frac{1}{2}$ miles, it amounts to 750 atmospheres; and water, which ranks amongst the least compressible of all known compounds, would be compressed, at a depth of twenty miles, to $\frac{1}{20}$th of its original volume*. Computations of this kind have long been in vogue; and, as before stated, the extraordinary nature of the conditions they involve has led to a sort of unquestioning belief that, where they are present, all life is impossible. The chief fallacy has consisted in the introduction of cases which are parallel in no essential particular. Thus, the effects of this stupendous pressure has been viewed in relation to its effects on fishes having closed air-bladders, or, at all events, bladders only capable of being cleared of their contents by a very slow process; and, as a matter of course, but one

* See 'Physical Geography,' by Mrs. Somerville, vol. i. p. 325.

inference could be arrived at, namely, that such swimming-bladders would collapse.

Again, pieces of wood retained for an hour or two at a depth of a thousand fathoms are said to have become so increased in density as to "sink like stones." Captain Scoresby relates an example of a boat having been dragged down by a whale to such a vast depth that the wood of which it was formed sank like a stone, not only immediately after its recovery from the sea, but "for a year afterwards." Here, then, it would appear that the whale must have descended as deep as the boat, or probably deeper, inasmuch as the latter was attached to it by the whale-line and harpoon. Other instances have at various times been recorded of harpooned whales having dived down vertically to immense depths, and, in some cases, having been killed by coming into forcible contact with the bottom!

But, notwithstanding the vast muscular power possessed by the gigantic Cetaceans, and the momentum attained by their bodies when diving with extreme speed, we should hardly be justified in looking to them for evidence tending to prove that life can be maintained at depths exceeding 500 fathoms. This will perhaps be rendered more apparent when it is recollected that the whale is not constituted to live at any great depth, and that its specific gravity is such as to be in equilibrium with the surrounding element almost immediately below the surface. Hence, even at the moderate depth of 500 fathoms, its body would be exposed to such a degree of compression as would at once paralyse, if not destroy, life. Thus, if we take the case of a medium-sized whale, say 50 feet long, and with an average diameter of 10 feet, the total pressure on the surface of the body would amount to upwards of 11,000 tons. It is supposed that the peculiar conformation of the Cetacean skin, throughout the substance of which the blubber is secreted, enables the creature to sustain a degree of pressure that would otherwise be intolerable—a pressure stated as "sometimes amounting to a ton upon every square inch"*. But, inasmuch as the whole of the observations on the depths to which whales have been supposed to penetrate are based on the quantity of line run out, and its direction on entering the water, it is much more likely that, as in the case of soundings taken where deep-seated currents prevail, the direction is changed from a vertical to a horizontal one,

* See Professor Carpenter's 'Zoology' (London, 1857: 2 vols.), vol. i. p. 239.

long before the extreme depths were reached at which these tremendous pressures exist*.

In the case of pieces of wood and meat, and corked bottles containing air, which have been sent down to great depths in order to demonstrate the effects of pressure, it is evident that precisely those conditions are present which are never to be met with in creatures constituted to live under it. In short, they prove too much; for they prove clearly that, in defiance of all obstacles, a state of equilibrium is rapidly engendered between the interior and the exterior of the wood, the mutton, and the bottles, and that whensoever this takes place no further change is experienced. If suddenly submerged, that is to say, before the pressure has time to overcome the resistance of the cellular and fibrous tissues of the two first and of the cork employed in the last, diminution of bulk and consequent compression of the structure must inevitably result; but, on the other hand, if the submergence be gradual, the diminution in bulk is by no means a necessary consequence, and the change brought about is a simple displacement of a lighter medium by a heavier, according to a well-known law of fluids. The example so often cited of the cork being at first forced inwards, and subsequently redriven into the neck of the bottle so as to close it as effectually as before, clearly shows that its cellular tissue has undergone compression and redilatation. Hence these experiments can only be regarded as illustrating phenomena which are not confined to extreme depths in the ocean, but may be seen in operation in a modified degree in every piece of floating organic matter around us.

The faculty possessed by some ground-living fishes of accommodating themselves, in certain localities, to depths greatly in excess of those usually frequented by them is very remarkable. Thus, several of the Cod tribe have a vertical range from 10 to 200 or even 250 fathoms, whilst a large number of species inhabit depths ranging from 10 to 100 fathoms. But, according to M. Pouillet†, certain fishes have been obtained by him from a depth of 550 fathoms, that is,

* Since the operation of getting an "up-and-down" sounding is attended with considerable difficulty, even when undertaken with a sinker of the shape best fitted to descend vertically, and a line little thicker than an ordinary pencil, it may readily be imagined how vastly the chances of an incorrect estimate, both with regard to depth and direction, must be increased, where the line employed is three-quarters of an inch thick, and a wounded monster is fast to the end of it.

† 'Elémens de Physique Expérimentale,' tom. i. p. 187.

3300 feet, where the pressure amounts to more than 100 atmospheres. Now, it is quite as difficult, in reality, to believe that a creature constituted to live near the surface, where the pressure does not exceed two or three atmospheres, could adapt itself to sustain a pressure of 100 atmospheres, as it is to conceive that a fish ordinarily living under this amount could sustain five times as much more pressure; for the moment it is admitted that the same species may accommodate itself to widely varying depths, the principle of progressive adaptation comes into play, and we are warranted in assuming that very widely differing degrees of pressure and other collateral conditions may be encountered, provided the transition from one to the other be sufficiently gradual, and, further, that the more simple the organism, the more fitted will it be to undergo them with impunity.

It has already been shown that the human frame is able to undergo a diminution of nearly one-half the normal atmospheric pressure present at the sea-level, if gradually encountered. Now, although the degree of tolerance involved in this change of conditions seems to bear no comparison with that which we suppose must be necessary to enable an animal to bear several hundred times the normal pressure it is used to, there is a very important difference between the primary conditions existing in the two cases, which renders the comparatively slight reduction of atmospheric pressure much more determinate in its effects on the one than the vastly increased amount of pressure on the other. Thus, assuming the solids, fluids, and gaseous contents of the human frame to be in equilibrium under the normal pressure at the sea-level, and that each of these portions of the body is subject to a different rate of expansion and contraction, it follows that this state of equilibrium must become more and more disturbed as the atmospheric condition becomes more abnormal. Hence we can readily account for those painful sensations which are experienced in suddenly ascending to great elevations, or descending, as in the diving-bell, through depths which engender even greater and much more sudden modifications.

On the other hand, in the case of all water-breathing creatures, inasmuch as there are no gaseous contents present, and the circulating fluid is of the same or very nearly the same specific gravity as the surrounding medium, and every portion of the structure is completely pervious to fluids, either by its porosity or through endosmotic action, the state of equilibrium remains undisturbed; and,

as already stated, no injury accrues, provided the transition from one degree of pressure to the other be sufficiently gradual.

In the case of creatures generated at great depths, and migrating to higher zones, the same law would apply, time being the essential element in rendering the transition practicable and safe to the creature. The Ophiocomæ obtained from a depth of 1260 fathoms (nearly a mile and a half) were not only alive when they emerged from the water, but continued to move their rays freely for a quarter of an hour afterwards. It is to be regretted that, in my anxiety to preserve the specimens, no effort was made to keep some of them alive in their natural element. But, even in the absence of further evidence, the one great fact remains, that these starfishes retained their vitality for nearly an hour, during which period they passed through every gradation of pressure ranging from a ton and a half on the square inch to only 15 lbs. Accordingly, since there are no grounds for supposing that star-fishes, or any other creatures constituted to live in the ocean, could undergo a transition from a high to a low degree of pressure with greater safety than one from a low to a high degree, and the abrupt change of conditions was borne in the present case without producing instant death, it is but fair to assume that, under a sufficiently gradual transition, *any* given amount of pressure might become supportable.

Respiration may be regarded as the primary vital function of every animate organism. Without it the independent life of the individual, whether animal or plant, cannot have a beginning; and on its permanent interruption, existence ceases. In so far as we know, and judging from all analogy, this law holds good in the lowest as well as the highest order of being. The mechanism of respiration may be more complex in one than in the other; but, so far from the phenomena being wonderful in proportion as they are complicated, the opposite of this proposition is correct, and we find it difficult to comprehend how the humblest tribes, both of the animal and vegetable kingdoms, in the absence of anything like specialized structure, can nevertheless bring about the same results. As is well known, in the case of air-breathing creatures the act of respiration consists in the absorption into the blood of oxygen derived from the atmosphere, and the exhalation of carbonic-acid gas—the interchange taking place by means of the lungs, and the required effect being produced on the blood. In the case

of what are termed water-breathing creatures, the phenomena are essentially the same, inasmuch as the supply of oxygen, though not derived immediately from the atmosphere, is obtained from a certain quantity of atmospheric air present under all circumstances in waters fitted to be the habitation of organized beings.

Any of the causes which materially diminish the supply of atmospheric air tend to impair vital energy, and, if sufficiently protracted, to destroy life. Thus, fishes and all other aquatic animals die almost immediately if placed in water which has been deprived of its air by boiling.

Under these circumstances, the due aëration of the waters of the ocean constitutes one of the most important conditions of marine life *; and it becomes a question of the highest interest to trace the process whereby it is brought about in these deep abysses which would seem, at first sight, to be completely beyond the pale of atmospheric influence.

It is still a disputed point whether the oxygen and nitrogen of the atmosphere enter into chemical combination, or simply constitute a mechanical mixture. Whichever view is correct, the union takes place in determinate proportions —namely, one volume of oxygen to four volumes of nitrogen; and these remain constant under every degree of rarefaction and compression, and at all temperatures short of combustion.

Although the above may be regarded as the normal composition of atmospheric air, it is certain that the present order of life on the earth could not be maintained were these the sole elements present. Even animal life, which, for anything that we know to the contrary, depends on the respiration of air thus constituted, would speedily become extinct, inasmuch as it is dependent on the previous manifestation of plant-life, and plants require for their respiration and growth carbonic acid, aqueous moisture, and ammonia. Now, by a wondrous system of compensation, the gases evolved during the processes of animal respiration, combustion, and fermentation, are exactly those which minister to the respiration and nutrition of plants; whilst plants, in their turn, exhale the gas which is essential to the life of animals, and consume those elements which, if permitted

* It is necessary to state that aëration is made secondary to temperature, inasmuch as under the existing order of nature it is impossible to imagine the proportion of air present in the waters of the ocean so altered as to endanger the life of creatures inhabiting them; but it is far from being so to conceive the occurrence of changes of temperature which might not only endanger but destroy it.

to accumulate in the atmosphere to an indefinite extent, would render it unfit for the support of all organized beings whatever.

If we turn to the ocean, we may find the conditions modified but not changed. For whilst atmospheric air, as already pointed out, is indispensable to the respiration of water-breathing (or, in other words, marine) animals, carbonic acid is equally indispensable for that of marine plants. It has been customary to regard carbonic acid as present in sea-water in comparatively minute quantity, and, as if in apology for this minuteness, to maintain that it could not "possibly be wanting in a fluid in which a far greater number of animals breathe than on land" *. I shall hereafter endeavour to prove that the supply of this gas demanded for the ocean is infinitely in excess of the quantity usually ascribed to it, and that, whilst it is derived by absorption from the atmosphere, the actual quantity poured forth into the atmosphere during the processes of animal respiration, combustion, and fermentation could be reduced by no other means than this absorption to the small proportional amount discoverable by analysis at any single period.

In the same manner that the aqueous vapour present in the atmosphere is merely held in suspension, so are the gaseous bodies present in sea-water merely held in solution; that is to say, in neither instance does a chemical combination occur under ordinary pressure. Water absorbs a certain quantity of all gases, some, however, in much larger quantity than others. Thus, whilst it absorbs nearly volume for volume of carbonic acid under ordinary pressure, it can only take up about $\frac{1}{29}$th of its volume of oxygen and $\frac{1}{40}$th of nitrogen. When the two latter gases occur in the shape of atmospheric air, the quantities are slightly modified—rather more oxygen, and rather less nitrogen, being absorbed. But, under an increase of pressure, the proportion of gaseous matter taken up by water is very greatly increased, as may readily be understood when it is borne in mind that fluids are nearly incompressible even under extreme pressure, whereas gases are easily compressible, and that the relative volumes of the gas absorbed and the fluid absorbing are acted on in widely different degrees.

The mode in which the solution of atmospheric air in sea-water is brought about is but imperfectly understood. It is probable that the agitation of the surface resulting from the action of winds and currents assists in effecting

* Bischof, vol. i. p. 116.

the admixture; but since we know that the operation of these causes extends but a little way below the surface, and that, far within the limits to which animal life has heretofore been supposed to range, their action is altogether arrested, it is evident that the absorption of air must be mainly dependent on some constant property of fluid and gaseous matter unconnected with these agencies.

Since the tendency of fluids to absorb gaseous bodies is constant under all circumstances, although, as already stated, the quantity they are capable of appropriating increases with the pressure, it follows that, the deeper the stratum of water, the greater must be the amount of gaseous matter held in solution by it. In illustration of the manner in which a column of sea-water becomes saturated with its complement of gaseous matter, let us suppose atmosphere and ocean to be brought into contact for the first time, and the process of absorption to be commencing. As soon as the superficial stratum of water received its full charge, it would transfer a portion to the stratum immediately below it. This stratum, when fully charged, would in like method transfer a portion to the succeeding one, receiving a fresh supply from the stratum above, and so on through the entire series; whilst in order to meet the demand thus continually increasing from below, an uninterrupted absorption would be carried on at the surface, the lowest stratum being the first saturated; whilst the highest would serve as a channel of transmission for the whole of those below it, and be the last to arrivé at the point of saturation, notwithstanding that its gaseous contents are the smallest in quantity.

Were the pressure equable throughout the entire vertical range of the column, the transmission of gaseous matter from above downwards would only proceed until the quantity absorbed in equal volumes of water was similar at the surface and at the bottom. But, inasmuch as the pressure increases with the depth, and the quantity of gaseous matter absorbed is in a direct ratio to the pressure, it is evident that the operation must be protracted until each stratum of water has received, through the entire series of strata above it, the quantity absorbable in virtue of the pressure it is subject to. On this being accomplished, but not till then, every portion of the column would be in equilibrium with the portions adjacent to it, and, accordingly, all further abstraction of gaseous matter from the atmosphere would cease, in the absence of any expenditure taking place from below.

It may, perhaps, be urged against this theory, that, instead of remaining in the state of equilibrium indicated, the tendency of gaseous matter would be to rise

and escape at the surface; but, inasmuch as the capacity to absorb a given quantity of such matter, under a given degree of pressure, admits of no variation, and it is clear that the affinity of the fluid for the gas is more powerful than any other counteracting influence, since otherwise absorption could not take place even at the immediate surface of the sea, there are no circumstances under which the evolution of the gaseous matter could occur. The example of ascending thermal springs charged with gases and salts is by no means a parallel one; for in these the column is circumscribed within solid walls, and each successive zone or stratum of water, in ascending, carries along with it its gaseous contents; and, as a necessary consequence of removal from a greater to a smaller degree of pressure, the disengagement of gas takes place. In the ocean there are no ascending currents of the kind; but even if there were, the conditions would be dissimilar, inasmuch as each portion of water ascending would instantly be replaced by fresh portions poured in under the same degree of pressure, and therefore charged with the same amount of gaseous matter. Hence, unless it can be shown that increase of pressure does not enable water to absorb a greater quantity of gaseous matter, it follows that the latter must always bear a direct ratio to the former.

It is far from my meaning to assert that the quantities of oxygen, nitrogen, and carbonic-acid gases absorbed by sea-water at any given depth would equal the quantity of one of these gases absorbed by the same volume of water under the same pressure, supposing no other gaseous or saline constituent to be present in it, but only that some increase of absorbent capacity must take place for every increase of pressure, and, hence, that the increased quantity of one of these gases absorbed at the base of the column of sea-water, or at any point intermediate between the sea-bed and the surface, would bear a definite ratio to that of the other gases absorbed along with it. It is well known that, in order to ensure the greatest amount of absorption by a liquid, it is essential to free it, in the first place, by boiling or otherwise, of all other gaseous matter, and, moreover, that the absorbent power is greatly diminished by the presence of saline substances in solution. Now sea-water contains both other gases and as much as 3·527 of saline substances in solution, and it is highly probable that the proportion of the latter increases with the depth. Therefore we should naturally expect to find the increase of absorption moderate in comparison with what would take place were the water in a state of purity.

According to the most recent analyses, the mean amount of carbonic acid in the atmosphere is estimated at about 1 part in 1000 by weight. In the various notices of the gas it has been customary to state that this proportion, although unexpectedly small, is nevertheless sufficient to supply the entire vegetable kingdom with the carbon of which their solid tissues is composed. If my theory be well founded, this 1 part in 1000 does not represent the quantity originally present in the atmosphere, but only the residue which remains after supplying the requirements of the ocean and plant-life; in other words, it is the floating deposit destined to meet current expenditure, the amount being kept up by the processes already referred to.

According to Vogel, in 10,000 parts by weight of sea-water from the Mediterranean and the Atlantic there were present 1·1 and 2·23 parts, respectively, of carbonic acid—a quantity extremely small, and yet declared to be sufficient, not only to retain the whole of the carbonate of lime actually present in sea-water in solution, but five times as much. According to some valuable experiments conducted on board the French ship 'Bonité,' the fact has been clearly established that the quantities of atmospheric air, and more particularly of carbonic-acid gas, increase with the depth. The analyses, as cited by M. Bischof†, are so striking, and exercise such an important bearing on all questions relating to the deep-sea deposits, that I am induced to quote them in detail.

Time and place.	Depth in Paris feet.	Gas in 100 volumes of water.	Gases.			Sum of oxygen and carbonic acid.
			Oxygen.	Carbonic acid.	Nitrogen.	
1836. South Sea.	0	2·09	0·13	0·22	1·74	0·35
	349	2·23	0·23	0·40	1·58	0·63
1837. Bay of Bengal	0	1·98	0·11	0·28	1·59	0·39
	997	3·04	0·10	1·77	1·17	0·87
1837. Bay of Bengal	0	1·91	0·12	0·25	1·54	0·37
	1495	2·43	0·14	0·73	1·56	0·87
1837. Indian Ocean	0	1·85	0·18	0·23	1·44	0·41
	2243	2·75	0·27	0·96	1·52	1·23
1837. Atlantic Ocean. . . .	1994	2·04	0·08	0·59	1·37	0·67

* The specimen of surface-water was lost in this example.

† See 'Chemical and Physical Geology,' by Gustav Bischof. Translated from the German, and published by the Cavendish Society, vol. i. p. 114.

In opposition to the views advanced by me with regard to the increase of atmospheric air in the waters of the ocean with the increase of depth, I would draw attention to the experiments of M. Biot on the gaseous contents of the swimming-bladders of fishes*. It is stated by Sir Henry De la Beche, on the authority of M. Biot, that whereas the swimming-bladders of fishes caught near the surface were filled, not with pure atmospheric air, as might have been expected, but with nearly pure nitrogen, the swimming-bladders of such as were brought up from a depth of 500 fathoms were filled with oxygen and nitrogen in the proportion of 9 of the former to 1 of the latter—the conclusion arrived at from these facts being that there was a difficulty in obtaining nitrogen at great depths, whilst it was procurable in abundance near the surface, and hence that atmospheric air was more plentiful in the latter than in the former situation.

It is worthy of note, however, that these proportions do not tally with the fact that in a given volume of water, under ordinary pressure, the quantity of oxygen is rather greater, and that of nitrogen rather less, than is compatible with the ratios borne by these two gases to each other when in combination as atmospheric air. For, since the normal ratio of oxygen to nitrogen is very nearly as 1 to 4, and the relative quantities of these gases absorbed by water are as 3 to 2, and assuming with Sir H. De la Beche that the quantity of atmospheric air present decreases with the depth, we should expect to find more oxygen present in the swimming-bladder of the fish taken from the surface than in that taken from deep water. It should be borne in mind, moreover, that the swimming-bladder is in no way connected with respiration, and that it only serves to regulate the specific gravity of the fish; and hence the secretion, when at the greater depth, of that gas which is considerably heavier than the other is precisely what might be looked for when the object to be attained is the maintenance of equilibrium with the surrounding medium. But it has already been stated that the normal ratios of the two gases, as they exist in atmospheric air, are modified to a very considerable extent when they are held in solution by water, oxygen being taken up in larger quantity, and nitrogen in less, and the former of these gases constituting $\frac{8}{9}$ths of the water itself. Hence assuming, as is the case, that the gaseous contents, whatever they may be, of the swimming-bladder are secreted through the circulation, and not imbibed directly into its

* 'Researches in Theoretical Geology,' by Sir H. De la Beche, p. 229.

cavity, we are warranted in supposing that the quantity of oxygen found in it is larger in deep water than at the surface, owing to that gas being more essential to vital action, being present in greater abundance, and approaching more closely to the specific gravity of the surrounding medium than nitrogen. This view is borne out, moreover, by the 'Bonité' analyses, which show the tendency of the nitrogen to decrease with the depth.

There is another very remarkable property of gases which demands notice, although it is impossible, in the present state of our knowledge, to say how far this property may operate in modifying the combinations of sea-water and its various ingredients—namely, their liquefaction under great pressure. It has been shown that, although the degree of pressure necessary to produce the liquefaction of a given gas is constant at the same temperature, as the temperature decreases, so does the amount of pressure requisite to produce the effect diminish. Amongst the elementary gases, chlorine and cyanogen liquefy under the smallest amount of pressure, and at nearly ordinary temperatures. Oxygen, on the other hand, which is so refractory as to resist the extreme pressure it has heretofore been subjected to, when combined with an equal volume of the vapour of sulphur, as sulphurous-acid gas, becomes liquid at a temperature of 45° Fahr. under a pressure of only two atmospheres. In the same manner hydrogen, which in its separate state proves equally refractory, on being mixed with one-third of its volume of nitrogen so as to constitute ammoniacal gas, becomes liquid under a pressure of about six and a half atmospheres, at 50° Fahr.; whilst, by a remarkable change of properties, chlorine, which alone is readily liquefiable, if united with an equal volume of hydrogen requires a pressure of forty atmospheres; and hydrogen and oxygen, both of which gases in their separate state resist all pressure that has been applied to them, when combined to form water continue liquid under a pressure considerably below that of a single atmosphere. Lastly, carbonic-acid gas, which, at a temperature of 32° Fahr., requires thirty-six atmospheres to cause it to become liquid, at 14° Fahr. only requires twenty-seven—a degree of pressure far short of that it is subject to in the lower zones of the sea.

It is probable that the saline and mineral substances present in sea-water exercise a much more marked effect on the formation of the organic deposits of the deeper zones of the ocean than has been admitted under the antibiotic view

so often referred to. From the nature of the difficulties by which the inquiry is surrounded, not only is the chief portion of our knowledge regarding the deep-sea bed rather of a theoretical than a practical kind, but, unfortunately, it must long continue to be so. It is doubly expedient, therefore, to test this knowledge by the light of every fact that science or accident may throw in our way. Thus, notwithstanding all that has been achieved by chemistry and mineralogy, it still remains an open question whether the great limestone strata were precipitated from waters holding the mineral in solution, or whether the separation of the calcareous matter was a vital act involved in the construction of the shells of creatures holding the lowest rank in the scale of being. In like manner we are not in a position to state definitely the manner in which the siliceous concretions of the Chalk and the Carboniferous limestone were produced. Few persons now-a-days regard the calcareous deposits as having resulted from chemical, or the siliceous concretions from mechanical action; but, although the presence of the shells of the Foraminifera in immense profusion in some limestones supports the view that the animals to which they belonged effected the separation in question, there is no such proof forthcoming in the case of the altered limestones. If we examine the siliceous concretions, our perplexities increase rather than diminish; for whilst remains of siliceous-shelled organisms are to be met with in them, it is very remarkable that they do not belong to the family of siliceous-shelled Rhizopods which, next to the Foraminifera, are most largely represented at the bed of the ocean, namely, the Polycystina, and there is no authenticated example, up to the present period, of a Polycystine shell having been detected in a flint. From the nature of the hydro-silicates, we could hardly expect to find the forms of siliceous organisms preserved; hence it is possible that the mineral atoms of the Polycystina have become merged, as it were, into the substance of the masses. But, since we constantly detect siliceous spicules of sponges, which have not yielded to disintegration though similarly formed, it is difficult to reconcile the apparent anomaly. If we regard the concretions as principally made up of sponge-spicules, the case is but little altered; for the pseudomorphs of the calcareous shells of the Foraminifera are plentiful in their substance, and indicate that the conditions under which they were formed and silicified were such as might have been shared by the testaceous Rhizopods generally.

Under these circumstances it may not be out of place to review, as far as the limited data permit, the conditions under which the most important constituents of sea-water present themselves at great depths.

According to Bischof*, the total quantity of saline matter present in water from the Pacific, Atlantic, and German Oceans (as deduced from the analyses of Bibra) amounts to 3·527 per cent.; whereas the several ingredients occur in the following proportions:—

Chloride of sodium	75·786
Chloride of magnesium	9·159
Chloride of calcium	3·657
Bromide of sodium	1·184
Sulphate of lime	4·617
Sulphate of magnesia	5·597
	100·000

It will be seen, on reference to this table, that carbonate of lime and silica, the materials which enter so very largely into the formation of the shells and hard parts of the marine Invertebrata, are omitted. This is the more remarkable since the geological phenomena involved in the presence of these substances in sea-water may justly be regarded as amongst the most important and wonderful with which we are acquainted. For, although carbonate of lime and silica occur in proportions which appear small when compared with the mass of the ocean, they are nevertheless as essential to the existence of marine organisms of every kind as the carbonic-acid gas which is present in the atmosphere in still more minute quantity is essential to terrestrial plant-life,—the solid structure of the former being composed of carbonate of lime, of the latter of carbon. In both cases, moreover, the demand and supply of the material are balanced with such unerring nicety, that the failure of either one or the other could not take place without altogether disturbing some of the existing conditions of the globe.

It is stated by Bischof† that the vast quantity of carbonate of lime brought down to the sea by rivers, and the uninterrupted formation of the shells of testaceous animals, are of themselves *primâ facie* evidence of the presence of carbonate of lime, and that "the carbonic acid contained in sea-water will constantly dissolve carbonate of lime when present at the bottom"; whilst the fact of "the water being so far below its point of saturation as regards carbonate of lime can

* 'Chemical and Physical Geology,' vol. i. p. 379. † Ibid. p. 109.

only depend on the constant separation of the carbonate by testaceous animals." It is also mentioned, on the authority of Dr. Davy, that carbonate of lime occurs chiefly along coast-lines, and that it was only detected to the extent of 1 part in 10,000 in water from Carlisle Bay, Barbadoes, whilst in the neighbourhood of the volcanic island of Fayal the quantity was so small as to be barely discernible, and in the open sea between the West Indies and Europe it was altogether absent! Forchhammer, on the other hand, detected it in all sea-water.

The specimens of water analyzed by Bibra were obtained at a depth of only a few feet below the surface, with a single exception in which the water was brought up from 70 fathoms. Since, in the absence of any distinct statement to that effect, it is improbable that the specimens analyzed by Dr. Davy were obtained from great depths, or indeed elsewhere than at the surface, his observations only show that the carbonate of lime met with in the superficial stratum of water is derived principally from terrestrial sources; and that at a distance from coast-lines, in volcanic regions where the limestone-rocks are either wanting or covered by igneous deposit, or in the open ocean where the depth is too great to allow of any supply of the carbonate being furnished from lime held in solution or calcareous deposits at the bottom, it is entirely absent.

According to M. Bischof, water containing only one-tenth of the quantity necessary for saturation can dissolve as much carbonate of lime as if it were saturated; but since the quantity of carbonic acid present in sea-water is sufficient to dissolve five times as much carbonate of lime as is to be found in it, M. Bischof infers that its maintenance at a point so far below that of saturation must be due to the constant abstraction of carbonate of lime by testaceous creatures. He further states that since water saturated with carbonic acid is capable of dissolving only 0·1 per cent. of carbonate of lime, and under ordinary atmospheric pressure water contains its own volume of carbonic acid, a saturated solution "would contain 0·2 per cent. by weight, or ten times as much as is necessary for the solution of carbonate of lime to saturation." And, lastly, he argues that water saturated with carbonic-acid gas, even under high pressure, cannot dissolve more carbonate, because, if it did so, ascending springs would deposit their carbonate of lime, and choke up their channels, the moment the ascending stream became subject to a diminished degree of pressure *.

* 'Chemical and Physical Geology,' vol. iii. p. 171.

In stating the reasons why the gaseous contents of a column of sea-water cannot be discharged at the surface, I endeavoured to show that no analogy exists between the phenomena and those observable in ascending thermal springs in which a constant discharge takes place. If my views are correct, it is obvious that the arguments apply as forcibly to the saline as to the gaseous contents, since the same law which prevents the escape of the gaseous matter contained in each succeeding stratum will enable each to retain in solution its full complement of saline matter, so long as saline bases are supplied to the ocean.

Analyses of water taken from different latitudes and seas show that the quantities of saline ingredients vary from local causes. Thus, it has been found that in the neighbourhood of the equator, where rain-fall and evaporation are both excessive, they counterbalance each other, and the specific gravity of the surface-water and the proportion of solid matter undergo but trifling modification; but in sub-arctic regions, where the accession of fresh water is excessive during one season of the year, and evaporation at no time takes place to any great extent, the effect is much more conspicuous. The admixture of fresh water with that of the sea takes place gradually, owing to the inferior specific gravity of the former, but its influence extends to considerable depths. It is of the greatest importance, therefore, that water obtained from these latitudes for analytical purposes should not be taken from the surface, and that we should look to the deep circulation of the ocean for that equable diffusion of its various constituents on which the equilibrium and permanence of the whole depend.

It is worthy of remark that the calcareous deposits now forming over a large portion of the Atlantic and probably of all great sea-beds occur generally at great distances from coast-lines, and always in deep water; whereas coral-reefs, which derive their calcareous matter from the same source, are said to be formed in shallow water, although, through the subsidence of the sea-bed, these bases often extend to vast depths, and the reefs themselves may occur in what is now mid-ocean. Of the rate of growth of coral-reefs very little is known beyond the fact of its being extremely gradual. Of that of the Foraminiferous deposits nothing of a definite character has as yet been ascertained. Accordingly we are not in a position to declare whether the demand for carbonate of lime, in a given time, is greater in the superincumbent water of the coral-reef or the Foraminiferous deposit. But, assuming the demand to be equal in equal periods,

it is difficult to account satisfactorily for the presence of carbonate of lime in the shallow waters near coast-lines, and its entire absence at the surface of the open ocean, unless we admit that the quantity of the salt increases with the depth, and that the lowest stratum of water is that in which the conditions most favourable to the growth of the Foraminiferous shell are present.

Again, since the quantity of carbonic acid present in sea-water increases with the depth (as proved by the Bonité analyses), and the loose nature of the upper layer of the Foraminiferous deposit makes it pre-eminently liable to be acted on by a solvent, it is not improbable that a portion of carbonate of lime may be redissolved on the spot irrespectively of pressure, and that any deficiency in the supply may be made good, either by the quantity redissolved, or an increased quantity brought round by the deep oceanic circulation. If these views are correct, it is obvious that the rate at which the increase of the deep-sea calcareous deposits takes place depends entirely on the rate at which carbonate of lime can be poured into the ocean by rivers, since no new deposits could be built up, did the separation of carbonate of lime from the water holding it in solution (which is essential to the growth of the shells) and the re-solution of the dead shells counterbalance each other.

Taking all these circumstances into consideration, it appears probable that the demand for carbonate of lime at the bottom of the sea is limited only by the supply; for, inasmuch as the quantity of calcareous matter introduced by rivers is so great that, in the absence of an unceasing drain upon it by calcareous-shelled creatures, its waters would very speedily become saturated and give rise to chemical separation, and since no such separation has been found to take place (in our own day at least), and the average amount of carbonic acid is not found to decrease, it is evident that, through the increase of the calcareous-shelled organisms, the quantity of carbonate of lime brought down in solution to the deeper zones of the ocean must be altogether disposed of.

But, apart from the reasons which render the chemical separation of carbonate of lime from water holding it in solution improbable, it may be mentioned that there is no example amongst the North-Atlantic soundings, nor, so far as I am aware, amongst any of the recorded soundings taken in other portions of the ocean, of a recent deposit of lime having been met with such as would result from supersaturation alone. On the other hand, there is abundant proof of a

portion of the mechanically formed calcareous deposits being at times re-dissolved by water holding carbonic acid in solution, inasmuch as the vast amount of minute amorphous particles almost invariably present is traceable to no other source than the disintegrated animal portion of the shells left behind after the re-separation of the carbonate of lime.

According to the analyses of Forchhammer*, silica (or silicic acid) was found in all sea-water examined by him, the greatest quantity being 0·3 in 10,000 parts of water. In its pure state it is insoluble in water, but yields to water containing carbonic acid. In this respect, the conditions favourable to the presence of carbonate of lime in the ocean are also favourable to that of silica. With the alkalies silica forms soluble salts, called silicates, which enter very largely into the composition of rocks; whilst, like carbonate of lime, it is constantly being conveyed to the sea by rivers, where it furnishes material for the mineral portion of Sponges, of the Polycystina with their allies, and the marine species of the Diatomaceæ.

Although the whole of these organisms (excepting sponges, which are composite) far exceed the Foraminifera in minuteness, they nevertheless constitute a considerable per-centage of some of the oceanic deposits. As is well known, extensive strata have been found in Europe, in Africa, and America, which are almost exclusively composed of the siliceous remains of the Diatomaceæ; whilst in some parts of America deposits occur of a mixed character, that is to say, in which the calcareous and the siliceous remains are associated in nearly equal proportions. It is a remarkable fact that all siliceous deposits, such as those of Bilin, the Berg Mehl, and Tripoli, which consist almost entirely of a few well-marked species that flourished in the immediate locality, are of fresh-water origin and never occur in the ocean; whereas in oceanic deposits, although the siliceous forms may predominate, they are never unmixed with calcareous or other mineral matter. Again, in those marine deposits in which the species of Diatomaceæ are sufficiently abundant and well marked to indicate that they had lived in the immediate locality, it may be taken for granted either that the water was shallow or that the deposit was formed along a coast-line, since no Diatomaceæ live at greater depths than from 400 to 500 fathoms. In the deep-sea beds, when Diatomaceæ occur, the characters of the species, their variety, and their limited

* Bischof, vol. i. p. 109.

numbers at once show that they had been drifted from distant shallows, or were free-floating surface forms which had subsided to the bottom after death.

Whilst, as yet, we have no positive proof that the Polycystina live at extreme depths, it is a very significant circumstance that the large assemblages of these organisms hitherto met with in such a recent state as to indicate vitality occur in deep water, and that the forms taken alive at the immediate surface of the ocean in some latitudes are sufficiently distinct to prove that the same species do not occur at the surface and at the bottom without undergoing marked modification. On the other hand, there is reason to believe that some of the siliceous organisms met with in a living condition at the surface of the open ocean cannot live at any great depth, and that, from some peculiarity in molecular composition, the siliceous portion of their structure yields to the solvent power of the water. Thus the Acanthemetrina, a small group of organisms with siliceous frameworks of extreme symmetry and of such characteristic shape as to be readily distinguishable, occur in tolerable profusion in tropical and sub-tropical latitudes; but, strange to say, not a trace of their siliceous remains is to be found either in recent or fossil oceanic deposits.

The Barbadoes and other Polycystine earths have a calcareous basis derived from the same source and produced through the same organic agency as the pure calcareous deposits of the deep-sea bed; and, if we may judge from the composition of such Polycystine deposits as have heretofore been brought up by the sounding-machine, it would seem that all partake of the same character.

The character of the pure Diatomaceous earths of the Pliocene and Post-pliocene periods clearly denotes a difference in the chemical constitution of fresh- and salt-water deposits, which is of the highest importance as affording a means of determining in which of these it may have been formed, supposing the characters of the species to be uncertain; for, whereas the terrestrial species of Diatomaceæ are to be met with in water in which carbonate of lime is not necessarily present, there are no circumstances under which the marine species of Diatomaceæ and the Polycystina (all of which are oceanic) are to be met with in water devoid of that salt*.

* A systematic chemical analysis of the entire series of soundings hitherto obtained would in all probability throw a great deal of light on the geological phenomena of the globe, and, were the means forthcoming, it might very easily be accomplished.

Assuming, then, that carbonate of lime and silica are always present in sea-water, that carbonic acid increases in quantity with the depth, and that the solvent power of water as regards these two substances is due to the presence of this acid—that, on the deep-sea bed, in localities where carbonate of lime is said to occur in such minute proportions at the surface as to be inappreciable even by chemical tests, vast calcareous deposits are continuously being formed—lastly, assuming that the increase of testaceous creatures stands in a direct relation to the supply of the material of which their hard parts are composed *, we are unavoidably led to the inference that pressure, so far from restricting animal life to the higher zones of the ocean, may be regarded as one of the conditions most essential to its existence at extreme depths.

In addition to the substances already enumerated as present in sea-water, there are a few others which occur in still more minute quantities, or under such subtle combinations as to have led to their being omitted in most analyses. Regarding these, it is only necessary to state that iodine, fluorine, and phosphoric acid are detected, the first in marine plants, the second in sea-water itself, and the third in all organic remains as well as sea-water.

Of the conditions which determine the distribution of certain tribes of animals in shallow water, the composition and configuration of the bottom is one of the most important. Thus, rocky surfaces and sandy, gravelly, or muddy bottoms have each their special inhabitants, whose structure, taken in conjunction with the kinds of vegetable growth to be met with, induces them to select the localities best suited to them. There is no reason to suppose that the instinctive tendency to select certain descriptions of sea-bed in preference to others is less powerfully manifested or obeyed by creatures which live at great depths. For although we are warranted in assuming that the general character of the deep-sea bed is much more equable than that of shallower regions, there is ample evidence afforded by the soundings to show that the universal layer of soft deposit which has been declared by some writers to envelope its surface is very far from being constant, and that no more fatal mistake can be committed than to take for granted that mountain-ridges, abrupt precipices, and serrated rocks do not present themselves even where volcanic disturbance is unknown.

* The soft parts of these organisms consist of "sarcode," a proteine-compound the elements of which, oxygen, hydrogen, nitrogen, and carbon, are present in water.

It is obvious that deposit cannot take place universally over the bed of the ocean in the absence of a universal depositing-agency. Now, no such agency exists, but, on the contrary, there is clear proof that all the great calcareous deposits are of a local character; and, from what has been already said regarding the composition of sea-water at all depths and in all latitudes, it is evident that this local character is not attributable to a deficiency of calcareous material in the water, but to the absence (for reasons as yet beyond our comprehension) of the organisms by whom the separation of the material from its chemical combinations is effected.

The last condition which bears on the distribution of marine life is light—or (paradoxical as it may appear) that total absence of light which has been regarded by philosophers and poets alike, from time immemorial, as characteristic of the Deep.

Although light can hardly be said to exert any material effect on the geographical range of marine species, it constitutes an important element in determining their bathymetrical limits within the superficial zones of the ocean. For, notwithstanding it is the essential condition of vision, and it is impossible to conceive that eyes should have been bestowed on creatures for any other purpose than to see, we must bear in mind that the instinctive and well-marked preference for particular degrees of light manifested not only by creatures wholly destitute of visual organs, but by the vegetable kingdom in general, points to some more subtle sense than that of sight, and proves that its exercise may not necessarily be dependent on the light-giving rays of the solar spectrum.

We cannot tell why light affects different creatures in different ways; but its varying influence is far too decided and constant to escape notice. Thus we find certain forms living under the full glare of day, others avoiding it; some indifferent to every degree of luminous influence, others susceptible to the slightest. But, whatever the mode in which these idiosyncrasies manifest themselves, they pervade all the individuals of the same species, and we simply recognize the fact without knowing why or how it is brought about.

Again, although it has never been directly asserted that light is essential to animal existence, such a view has been in some measure fostered by the promulgation of two axioms,—namely, that light is essential to vegetation, and that animal life is dependent on the previous manifestation of vegetable life. Both of these

axioms are undoubtedly true in the case of terrestrial organisms; but the last is wholly unsupported as regards the lowest orders of creatures inhabiting the sea; for not only does every trace of light become finally extinguished at a depth comparatively speaking insignificant, but at a point considerably short of that at which some of the most highly organized littoral species habitually live. Thus, it is supposed that at 700 feet below the surface the realm of total darkness commences; and yet we know that many creatures indigenous to the deep-coral zone, and more especially certain fishes, enjoy a downward range of from three to five times that depth—that is to say, 2000 feet beyond the reach of the most attenuated sunbeam.

But whilst animal life has recently been shown to be present in vast abundance along the deep bed of the ocean, no vegetable life of any kind analogous to that with which we are acquainted has hitherto been discovered in a similar position. Vegetable structures unquestionably occur, and at times in considerable profusion; but there is no reliable evidence to show that these have lived elsewhere than near the surface. On the contrary, the appearance of the soft parts, in such as have been raised from depths exceeding 500 fathoms, indicates a molecular constitution differing materially from that observable in similar organisms which have been taken alive in shallow water. All analogy teaches us that plants cannot live in the absence of light. Under its influence the absorption of carbonic acid goes on, and the evolution of oxygen *. In default of it, a reverse process is set up. Light exerts no influence of this kind on animals; but, as already stated, since all terrestrial animals are ultimately dependent on vegetables for their food, and vegetables are thus shown to be dependent on light for their principal vital function, we are driven to the admission that ultimately light is essential to terrestrial animals. In the sea, the conditions under which plants respire are still unchanged. Light is essential to the absorption of carbonic acid and the evolution of oxygen. Even in the case of the lowest protophyte, this fact admits of demonstration; and it must be remembered that the vegetable forms met with in the deep-sea deposits belong exclusively to the latter class. Their occurrence

* It is certain that the organs of respiration of plants are confined to their green surfaces. Humboldt is stated to have found "a species of sea-weed of a bright-green tint, *although* it had grown at a depth of 190 feet," where it was computed no more than $\frac{1}{1500}$th part of the solar rays could penetrate. (See 'Manual of Physiology,' Professor Carpenter, p. 57.)

at extreme depths in a living condition would, therefore, involve the introduction of an exceptional law, for which there is no kind of precedent.

It is one of the most important offices of plants to purify the atmosphere of the element which would be poisonous to animals were it allowed to accumulate. How then, it may be asked, are the densely peopled waters of the ocean purified of the same poisonous element, if vegetation and light cease at the same limit; and under what other conditions than exceptional ones can marine animal life be maintained without the previous manifestation of vegetable life, as must be the case if it exists at extreme depths?

The answer to the first of these questions is obvious. The waters of the ocean seize on the carbonic acid exhaled by animals, and, as already shown when discussing the saline constitution of sea-water, the quantity of carbonate of lime present is sufficient to convert so much of it into a non-poisonous compound that the remainder is as innocuous as the carbonic-acid gas invariably present in the atmosphere. On the other hand, the indispensable oxygen is principally derived from the atmospheric air which has been absorbed by the water, the portion of it exhaled by marine plants being unimportant in comparison with the area and mass of the ocean.

I readily admit the difficulty of furnishing a solution to the second question, without appealing to a process of nutrition for which there is no acknowledged precedent. At the same time I submit that in the majority of the marine Protozoa—as, for instance, in the Foraminifera, Polycystina, Acanthometræ, Thalassicollidæ, and Spongidæ—there is much stronger ground for supposing that the process referred to is that by which nutrition is effected, than that complex functions of a kind analogous to those observable in creatures endowed with specialized organs, should be performed, by the simplest order of beings with which we are acquainted, in the absence of anything approaching to specialized structure. This subject will be more fully discussed in another portion of this work: at present it is only necessary to state that no exceptional law is invoked, but, on the contrary, that the proof of these organisms being endowed with a power to convert inorganic elements for their own nutrition rests on the undisputed power which they possess of separating carbonate of lime or silica from waters holding these substances in solution. In other words, if it can be shown that these organisms are able to produce a chemical separation of inorganic

elements in order to construct their shells, we are warranted in supposing they may also apply the elements not needed for that purpose to the nutrition of their soft parts; especially since the remaining elements are those which, when united, constitute the proteine-compound of which their soft parts are invariably composed. We may endeavour to establish a definite line of demarcation between the two great kingdoms of nature; but if we unbiassedly examine the life-history of the simplest forms on either side—as, for example, a cell of *Collosphæra* and a cell of *Navicula*—we shall find ourselves reduced to the admission that the vaunted boundary-line is empirical. If this be admitted, the grand distinction between the animal and the plant is destroyed—at least in the lowest tribes—and we discern in the liberation of a portion of the oxygen and carbon of the carbonic acid, of the hydrogen of the water, and the nitrogen of the atmospheric air, a vital act heretofore regarded as characteristic only of the vegetable kingdom. In short, the same process yields shell-material and food; and we discover that the last link in the series is derived, not from the vegetable world as we have heretofore been taught to believe, but from the inorganic. On the other hand, if this be denied, we have no alternative but to assume that the lower the creature the less need is there for special organs to perform special functions, and that the humble Rhizopod or Polycystine may digest, secrete, excrete, and (for all we can adduce to the contrary) think into the bargain!

Although the discovery, at extreme depths, of creatures devoid of visual organs would simply indicate that life is in no degree dependent on light, or on the previous manifestation of plant-life said to be inseparable from it, it is impossible to regard the occurrence, under similar conditions, of any of the more highly organized forms whose morphological relations involve the possession of organs of vision, without perceiving that upon this single fact hangs the question whether living creatures were originally constituted to live beyond the influence of light, or became gradually habituated to live at extreme depths. For it is manifest that the detection of the most rudimentary eyes would prove that the creatures possessing them had originally lived in shallow water, and that they had slowly accommodated themselves to the new and abnormal conditions by which they were surrounded—the sense of sight failing under the absence of the natural stimulus, and the organs of sight either degenerating or becoming obliterated from disuse, during a succession of generations.

The caves of Carniola, Adelsberg, Kentucky, and other localities furnish us with numerous examples of blindness in animals living beyond the influence of light, and enable us to trace the transition, from the simple loss of nervous sensibility to the partial or entire occultation of the external organs of sight, which is observable as the animals recede from the outer world and take up their abodes where the darkness is more or less complete. But inasmuch as blindness involves the presence, however rudimentary or degenerate, of a special set of organs, we should not be warranted in regarding creatures as originally created to pass their lives in the gloomy depths of these caves, or in any other position beyond reach of light, unless all trace of rudimentary visual organs was absent, and there was distinct evidence that the types to which such creatures belonged occurred elsewhere with those organs developed.

The identity of the *Ophiocomæ* obtained from an extreme depth in the North Atlantic with the *Ophiocoma granulata* of shallow water, although affording presumptive evidence that their ancestors, like their contemporaries met with on our own coasts, were not specially created to live in that position, is by no means a proof of the fact. The Ophiuridæ do not possess the so-called "eye-spots" of the Asteriadæ and Solasteriæ; and even if they did, the proof of these spots being true organs of vision supplied with nervous ganglia is far too feeble to be generally accepted. But, fortunately for the fate of the question, the *Ophiocomæ* referred to are not the most highly organized creatures that have been discovered at great depths, inasmuch as a "Crustacean of bright colours" is reported to have been brought up from 1400 fathoms, by Mr. Torell the director of the recent Swedish Expedition to Spitzbergen*. In the absence of a detailed description of this Crustacean, it would be premature to speculate on the indications afforded by its visual organs. But since the Crustaceans possess these organs without any exception†, the fact is of the highest value, as affording additional proof that creatures originally constituted to live in shallow water may gradually become acclimatized and live under the extraordinary conditions prevalent at extreme depths in the ocean.

With regard to the effect of light on the production of colour in animals, and,

* No official report of this expedition having appeared up to the present time, my information is derived from a letter which appeared in the 'Athenæum' of Dec. 7, 1861, which bears the stamp of perfect authenticity.

† See 'Anatomy of Invertebrata,' Siebold, English edition, vol. i. p. 325.

conversely, the absence of colour said by Forbes and nearly all other writers to ensue from diminution of light, I have only one series of facts to advance; but these appear conclusively to prove that, although intensity of light may, as averred, engender intensity of tint, the absence of light does not involve its loss or even its deterioration. The star-fishes obtained from a depth of 1260 fathoms were as brilliantly coloured as if they had lived their lives in the temperate zone and the shallowest waters; whilst, singularly enough, individuals of the same species dredged up from 100 to 200 fathoms in the fiords of West Greenland were of a dusky hue. *Acmæa testudinalis*, *Natica Grœnlandica*, *Chiton marmoreus*, *Hippolyte polaris*, *Boltenia picta*, *Ophiocoma bellis*, *Cottus glacialis*, and *Nullipora purpurea* were of the ordinary vivid tints. *Solaster papposa* and *Ophiura texturata* were alone slightly blanched; but this effect cannot be attributable to absence or diminution of light, since the same species occurred in shallow water, on the Labrador coast, with no greater development of colour. Lastly, as above stated, the Crustacean brought up by Mr. Torell from 1400 fathoms is described as "of bright colours." With these facts before us, and keeping in recollection the evidence that has been adduced to show that the creatures heretofore discovered at extreme depths are descendants of species that once flourished in shallow water, it appears reasonable to conclude that colour is a hereditary character, and that, inasmuch as a creature originally colourless cannot be made to assume a brighter exterior by subjection to a brighter sun, so neither can the natural colour of a creature be destroyed by removal to the opposite conditions. Deterioration of colour may, and undoubtedly often does occur, as in the case of animals removed from tropical to temperate regions; but the cases are not sufficiently numerous to be regarded otherwise than as exceptional. And when they do occur I cannot help thinking that we should search for the cause, not in the diminution of light, but in the impaired vital functions sure to attend removal from normal to abnormal conditions. Sickly animals, as well as sickly plants, lose their natural colour in tropical countries. In this case diminution of light can have nothing to do with the result. The more highly tinted fishes of our own latitudes degenerate in colour when out of season. And, lastly, there are examples of the reverse action being produced —that is to say, loss of colour by removal of animals or plants from their natural habitats in temperate regions to tropical ones. On these grounds I

venture to believe that the colours on the feathers of a bird, the wing of a butterfly, or the shelly covering of an Echinoderm are as purely hereditary as their various organs, and that, in artificially produced varieties, we must regard the condition as to light as only holding equal rank with numerous other secondary conditions, which produce their effects through the vital functions *.

Having thus described the various agencies on which the bathymetrical distribution of marine life depends, together with their modes of operation and relations to each other, it remains for me to prove (what I have heretofore been obliged to take for granted, in order to avoid endless repetition) that the star-fishes and other creatures, referred to as having been obtained from great depths, were captured in a living condition in the midst of their natural haunts.

When we take into consideration the more obvious changes which attend the removal of a living creature from the deep-sea bed to the surface, we can hardly fail to perceive that the chances are vastly against the detection of a remnant of vitality. For, although, as I have endeavoured to show, the increase of pressure which prevails at the bottom of the ocean exercises no more injurious effect on creatures formed to live under it than the pressure at the sea-level does on terrestrial animals, and there is every reason to believe that marine creatures in general, and the lower tribes in particular, can undergo very considerable alterations of it with impunity, the case becomes totally different when a creature is suddenly removed from a depth at which the pressure is estimated by tons on the square inch, to one at which it dwindles into a few pounds.

All animal tissues whatever are said to be originally formed of minute cells which are impervious to gases or fluids save through endosmotic action. But, since no free gaseous matter can exist permanently at extreme depths, the contents of such cells must be fluid and of the same, or nearly the same, specific gravity as the surrounding medium. This is a material character, inasmuch as it enables

* This view derives a singular degree of confirmation from the following facts, for which I am indebted to Mr. P. L. Sclater, the able Superintendent of the Zoological Society's Gardens. The brilliant plumage of the Scarlet Ibis (*Ibis rubra*), a native of Tropical America, and the equally brilliant scarlet of portions of the plumage of the Pine Bullfinch (*Pyrrhula enucleator*) and the Crossbills (*Loxia*), both natives of the northern parts of Europe, fade in an equally marked manner on their removal to this country; so that we have here presented to us deterioration of *the same colour*, in the one instance on removal of a bird from a tropical to a temperate climate, in the other on removal from a boreal to a temperate climate.

us to understand why the ocean never yields up its dead, and why, if tenanted by living things as we now know it to be, dead creatures never rise up to the surface to disclose the mystery of their past being. Decomposition may go on, but not putrescence. The molecular constitution of the particles of animal matter may be altered, and eventually, perhaps, their elements may enter into new chemical combinations; but, since no gaseous matter could be retained in a gaseous form within the cells or larger cavities of dead organisms, and the unfailing result of endosmotic action would be to place in absolute equilibrium with the surrounding medium every portion of the structure, no decrease of specific gravity can occur to cause it to ascend from its position. The same conditions would apply to living things originally formed to inhabit extreme depths, or acclimatized through a vast succession of generations; for although minute differences of specific gravity may exist between the fluid contained within their cavities and the medium in which they reside, there is no ground for supposing such differences to be greater than exist between the bodies of creatures constituted to live in shallow water and the medium in which they sustain themselves. If this view be correct, it explains how it is that the submarine fauna remains as immutably chained to the sea-bed under all circumstances as the terrestrial fauna remains chained to the surface of the earth. Here and there we detect the fossilized forms of oceanic creatures, some of which, in all probability, were denizens of deep water; but under one set of conditions alone does the detection become possible—namely, after the lapse of countless ages, during which sea and land have exchanged dominions.

Again, we should bear in mind that the oceanic Rhizopods, although perhaps more tolerant of change, in virtue of extreme simplicity of structure, than any other tribe of creatures with which we are acquainted, are, for the same reason, the least calculated to exhibit active vitality under sudden change. Under the most favourable circumstances, and only after the lapse of considerable time, do the shallow-water forms when in captivity exhibit pseudo-cyclosis or extend their pseudopodia. And hence, since it is in the last degree unlikely that those brought up from extreme depths should present these evidences of vitality, we must rest content with collateral proofs. Fortunately these are of a very satisfactory kind.

The minute calcareous shells of the Foraminifera are the most frequent and widely distributed organisms of the ocean. They occur in all seas in more or

less abundance. But there is one genus (namely, *Globigerina*) which may be regarded as essentially oceanic, since it is to be found in all latitudes, and at all depths ranging from 50 to 3000 fathoms. Its seat of maximum development is on the deeper areas of the sea-bed. There, like the sands of the shore, it strews hundreds of square miles of surface, and apparently builds up vast strata. The great superficial current of the Atlantic does not bear it away in countless multitudes from tropical coast-lines, nor does the body of the ocean itself constitute its habitation *. Nevertheless it is evident that there is an intimate association between the Globigerina-deposits and the Gulf Stream; for wherever we trace the one sweeping across the surface of the ocean, we are almost sure to detect the other resting on the sea-bed; and where we fail to trace the one, we almost as surely fail to detect the other. Thus, between the Faröe Islands and Iceland, between Iceland and East Greenland, and for a considerable portion of the direct route between Cape Farewell and Rockall, *Globigerina* is the prevailing form in the deposits; whereas between Greenland and Labrador, along the belt traversed by the Arctic current, and in a southerly direction along the coast of Labrador, it is either absent or occurs only in such very limited quantity as to prove that the conditions are favourable to its increase in the one case, and unfavourable in the other †.

It is obvious that if the deposits were due to the subsidence of organic matter transported by currents, instead of being formed of well-marked groups of species, or (as is sometimes the case) almost exclusively of a single species, they would *invariably* consist of heterogeneous assemblages of minute organisms derived partly from coast-lines, and partly from the oceanic regions previously traversed

* By sinking very fine gauze nets to considerable depths, I have repeatedly satisfied myself that *Globigerina* does not occur in the superficial strata of the ocean. On one occasion, a small bag was drawn up through 700 fathoms of water, in a locality where *Globigerina* abounded on the sea-bed, without entrapping a single shell.

† I have only had one opportunity of noting the characters of the recent Foraminiferous deposits of the southern hemisphere, namely, on the Agulhas bank to the southward of the Cape of Good Hope. There, in 100 fathoms water, I found *Globigerina* forming a nearly pure deposit (about 75 per cent.), the area of which was marked by a definite boundary-line, depending probably on the current which sets round the Cape from the eastward. This deposit differed in no respect from the deposits of the North Atlantic, except in the less massive character of the shells. Hence it would appear that massiveness increases with depth, or, as is more probable, that it is a consequence of it.

by such currents. Lastly, inasmuch as the shells of *Globigerina* surpass in massiveness and density those of any of the other minute structures met with in the deep-sea deposits, excepting the Polycystina—if we assume the deposits to be formed by the gradual subsidence of organic atoms from the transporting currents, it follows that the proportion of light forms to heavy ones would invariably be the greatest at the greatest distances from land,—a result which is not in accordance with observation.

The extreme lightness of some Foraminiferous deposits has been alluded to by Captain Maury, in his admirable work on the 'Physical Geography of the Sea,' as "suggesting the idea that the sea, like the snow-cloud with its flakes in a calm, is always letting fall upon its bed showers of these microscopic shells;" and he adds, "the ocean, especially within and near the tropics, swarms with life; the remains of its myriads of moving things are conveyed by currents, and scattered and lodged in the course of time all over its bottom: this process, continuing for ages, has covered the depths as with a mantle, consisting of organisms as delicate as the macled frost, and as light as the undrifted snow-flake on the mountain" *.

This flocculent character is distinctly observable on the immediate surface-layer of all deposits, and in a few cases, in which the quantity of extremely fine amorphous particles is excessive, it extends to some depth. Such is the condition observable in those localities where the Foraminifera are either absent or constitute the smallest percentage of the material. But in the majority of the deposits, the flocculence does not extend beyond half an inch or an inch below the surface, and it is then replaced by a stratum of the utmost tenacity. This marks the limit of the amorphous non-mineral particles, and the point at which the consolidation of the heavier atoms commences. Although satisfied of the correctness of that portion of Captain Maury's statement which describes "the *remains* of myriads of moving things as being conveyed by currents, and scattered and lodged in the course of time all over" the sea-bottom, I am unable to confirm by my own experience either in the North or South Atlantic that portion of it which relates to "showers of microscopic" (Foraminiferous) "shells." Free-floating Foraminifera are undoubtedly to be met with on the surface of the ocean, as well as free-floating Polycystina, Diatomaceæ, and other less known and

* 'Physical Geography of the Sea,' by Captain Maury. London, 1858: p. 265.

common organisms; but these never constitute the bulk of the deep-sea deposits, as *Globigerina* does. They live within reach of the surface, and are more frequently to be seen in tropical regions; but there is good ground for the belief that the amount of minute animal and vegetable life in tropical and extra-tropical latitudes is far more evenly balanced than has generally been supposed, and that the preponderance to which Captain Maury and other observers have drawn attention as characteristic of the tropics is dependent, not so much on the superabundance of forms within the tropics, as on the rarity of those favourable atmospheric conditions upon which the presence at the immediate surface of extra-tropical forms depends *.

Some of the Globigerina-deposits are of great purity; but I have reason to believe I originally overestimated the percentage of shells and débris, and that the singular absence of amorphous particles in the two specimens on which my estimate was based was due to percolation of water through the mass of the material during its progress from the bottom to the surface. The average proportion of shells varies from 70 to 85 per cent., the remainder consisting of amorphous particles and variable quantities of mineral matter, Polycystina, Diatomaceæ, Sponge-spicules, and not unfrequently fragments of Echinoderm structure.

Turning from the shell, which, in this as in the other Foraminifera, furnishes no characters distinctive of vitality, and, in the majority of the species, does not even enable us to pronounce whether they are recent or fossil, we find that there is nothing either in the quantity, the colour, the consistence, or the optical appearances of the soft parts to indicate that the *Globigerinæ* of the pure deposits do not live where they are discovered. From the difference in colour between the surface-layer of the deposits and the mass beneath, and also owing to the extreme tenacity of the inferior stratum, it appears probable that the living *Globigerinæ* are altogether confined to the former,—this view receiving additional support from the fact that the aspect of specimens taken from the surface corresponds with that of shells known to be alive, whereas the dingy look of those from the subjacent stratum corresponds with that of shells known to be dead. In one case the colour is a vivid but light burnt sienna, the fleshy matter viscid

* The observations of Dr. Joseph Hooker in the Antarctic Sea tend rather to prove a superabundance of the minute organic forms in its waters.

and inclined to coalesce again when crushed, and the retracted pseudopodia are occasionally seen forming minute bosses on the external surface of the shell; in the other, the colour is a dusky brown inclining to grey, the fleshy matter is not viscid, and there are no traces of the pseudopodia. Lastly, the definite boundaries of the Globigerina-deposits, to which allusion has already been made, afford presumptive evidence that the increase of the organisms is dependent on conditions prevalent on the spot, and consequently evidence of vitality.

The association of the more extensive Globigerina-deposits with the Gulf Stream and its several offshoots in the North Atlantic is dependent, I conceive, on the vast supplies of carbonate of lime brought down to it by the great rivers that discharge themselves into the Gulf of Mexico and the Caribbean Sea. Captain Maury combats the idea that the "Mississippi is the Father of the Gulf Stream," and quotes Captain Livingstone as having "overturned this hypothesis by showing that the volume of water which the Mississippi empties into the Gulf of Mexico is not equal to the three-thousandth part of that which escapes from it through the Gulf Stream." He also points out that the water of the Mississippi is fresh, whilst that of the Gulf Stream is salt; and that the waters of the Mexican Gulf and Caribbean Sea are salter than the waters of like temperature in those parts of the ocean through which the Gulf Stream flows, the phenomena being accounted for by the excessive evaporation which takes place in the waters poured into the Gulf Stream and Caribbean Sea by the great equatorial current*.

However true Captain Maury's view may be with regard to the other saline constituents of sea-water, I venture to think it cannot be so in the case of the carbonate of lime, or, indeed, the calcareous salts generally. These we know are essentially derived from fresh-water discharges. The surface waters of the ocean are those which contain the smallest quantity of calcareous matter. The great equatorial current is quite superficial, and on the African side it only receives the outpourings of two rivers, namely, the Niger and Senegal, which, though large, are much inferior in size and extent to the Amazon, Orinoco, Magdalena, Rio Grande, and Mississippi—one and all of which debouch into the equatorial current either before or after it sweeps into the Caribbean Sea and Gulf of Mexico, and pour forth into the waters destined to emerge again as the Gulf Stream the vast stores of calcareous matter they bring down from the interior of

* 'The Physical Geography of the Sea,' p. 26 *et seq.*

the American continents. The massiveness of the shells, in the greater portion of the Foraminiferous deposits obtained on the bed of the North Atlantic, clearly shows that the material of which they are composed is present in its waters in abundance. If the views suggested by me regarding the increase of carbonate of lime with the depth be correct, or even supposing the superabundant supply indicated by the presence of the calcareous deposits to be due to the uninterrupted supply of carbonate, irrespectively of its increase with the depth, the phenomena here indicated serve to corroborate them, and we have presented to us an example of disintegration of strata on the one hand, and reconstruction on the other, on the grandest scale that the earth affords.

The facts connected with the discovery of highly organized radiate animals at extreme depths may justly be regarded as establishing a new era in marine zoology; for, if we attentively examine their bearings, we shall find that, whilst they throw a flood of light on the conditions essential to the maintenance of life in existing seas, they serve at the same time to explain anomalies in the history of some of the older fossiliferous strata, and thus add another link to the chain that binds the Present with the Past.

In order to render apparent the full significance of the Star-fish sounding, I shall endeavour briefly to detail the geographical relations of the locality in which it was taken; the mode in which it was effected; the proofs that the creatures were captured at the bottom; and, lastly, the reasons for believing that, although originally a shallow-water species, these Star-fishes had gradually, and through a long series of generations, accommodated themselves to the abnormal conditions incident on the subsidence of the sea-bed.

The sounding was taken in lat. 59° 27′ N., long. 26° 41′ W., about halfway between Cape Farewell and the north-west coast of Ireland,—the distances being, from the nearest part of Greenland 500 miles, of Iceland (namely, the "Blinde Skier" rock) 250 miles, and the Rockall Shoal about 400 miles.

It is a very notable fact that the position thus indicated is within 100 miles to the north-eastward of that assigned to the "Sunken land of Buss" in old charts*; and that, at a spot about 100 miles to the westward, where the previous sounding was taken, a decrease of depth was indicated amounting to 512 fathoms. For, since it is in the last degree improbable that the shallowest

* See Diary, pp. 63, 64, and 65.

locality in this latitude should have been thus accidentally struck, and it is but reasonable to conclude that the spot laid down in the old charts as a "Sunken land" should still be the shallowest, there is good ground for supposing that the depth continues gradually to decrease from the westward locality, where it is 748 fathoms, to the reputed position of the Sunken land. The probability is enhanced, moreover, from the circumstance of its being only twelve miles to the eastward of the meridian laid down in the French map by M. Fleurieu as that of "Buss." Lastly, we find that if a line passing through the axis of volcanic action in Iceland (that is to say, extending from its north-easterly to its south-westerly extremity) were produced in the latter of these two directions, it would as nearly as possible cross the position of the Star-fish sounding and the "Sunk land" so often referred to. Now we know that subterranean forces have been in active operation in the direction of Iceland at a very recent period, and that a submergence has taken place of certain volcanic islands which were suddenly heaved up from the sea-bed. Apart from other evidence, this fact is obviously of less value than it would have been had the submergence of the islands taken place gradually; but, viewed in conjunction with the subsidence known to have been taking place for several centuries along the southern shores of Greenland, and in the absence of sufficient reason for repudiating the testimony of the early Scandinavian, Venetian, and French hydrographers, it leaves very little room for doubt that a vast area of the sea-bed, involving the whole of these positions, has shared in the submergence.

In all soundings demanding accuracy, it has been customary to determine the depth by one operation, and to secure the specimen of bottom by another. On the present occasion, the depth (1260 fathoms) having been ascertained, a new form of "deep-sea dredge"* was lowered; but, in consequence of its partial failure, a second apparatus (namely, the conical cup) was employed, 50 fathoms of line in excess of the recorded depth being paid out in order to ensure the unchecked descent and impact of the instrument at the bottom. The "dredge"

* The "deep-sea dredge" is really, what the name implies, a dredging- and not a sounding-machine. It was devised by the Chief Engineer of the 'Bulldog,' Mr. Roughton. Although somewhat imperfect, owing to the necessity for carrying out the design with such materials as were available at sea, it might readily be made a most efficient instrument. For natural-history purposes it is obvious that a dredging instrument would always be preferable to one which merely closes on such portion of the surface as it happens to come in contact with.

had already brought up a small quantity of unusually pure Globigerina-deposit and some small stones. The second instrument came up quite full of the deposit; but it was neither so free from amorphous matter, nor did it contain any of the small stones. Adhering, however, to the last 50 fathoms of line, which had rested on the ground for several moments, were thirteen *Ophiocomæ*, varying in diameter across the arms from two to five inches. None of these relaxed their grasp on emerging from their natural element, but continued, for a considerable period after detachment from the sounding-line, to move about their spine-covered arms, thus clearly proving that, although their continued adherence may have depended in some degree on clonic spasm caused by the diminution of pressure, or on the entanglement of their spines in the fibres of the hempen line, their vitality was at all events far from extinct.

Here then we have the accuracy of the first operation conclusively established by the two succeeding ones; the nature of the bottom brought up by the dredge verified by that procured in the conical cup; the proof that fifty fathoms and no more rested on the ground supplied in the correspondence of the three soundings; and, so far as the sounding apparatus is concerned, proof that the Star-fishes had no opportunity of attaching themselves to any portion of the line except that which rested on the bottom. If we examine the remaining evidences, we shall find that it is impossible to arrive at any other conclusion than that the Star-fishes were captured on the sea-bed itself, and not at any point intermediate between it and the surface.

Commencing with the habits of the hard-shelled Echinoderms, there is ample evidence of their being essentially ground-living animals—that is to say, unfitted both in virtue of their structure and specific gravity to raise themselves to any distance, or for any lengthened period, from the bottom. Edward Forbes states that "they are almost all free animals, creeping about at the bottom of the sea;" and adds that their coriaceous skin, which is commonly strengthened by calcareous plates or spines, "distinguishes them from the Medusæ, free-swimming animals of the most delicate and membranous texture"*. In Professor Owen's recent work on Palæontology, the characters of the Echinoderms are given as follows:—"Marine, commonly free repent animals, with the integument in most perforated by erectile tubular tentacles, hardened

* 'British Star-fishes,' by Edward Forbes. London, 1841: Introduction, p. 12.

by a reticulate deposit of calcareous salts, and in many armed with spines" *. Professor Rymer Jones describes the Ophiuridæ as having "the rays long and simple" (in contradistinction to *Comatula* and *Gorgonocephalus*), and says "they resemble the tails of so many serpents, but nevertheless are possessed of moveable lateral spines on each side of every ray, which, although but mere rudiments of what are seen in *Comatula*, may still assist in locomotion, or perhaps contribute to retain the prey more firmly when seized by the arms,—the rays themselves being composed of many pieces curiously imbricated and joined together by ligaments; so that they are, from their length and tenuity, extremely flexible in all directions, and serve not only for legs adapted to crawl on the ground, but are occasionally serviceable as fins, able to support the animal in the water for a short distance by a kind of undulatory movement" †.

Lastly, in the 'System der Asteroiden,' by Müller and Troschel, "the section of the Ophiuridæ which want the pedicellariæ and the anus is divided into two subdivisions, Ophiuræ and Euryalæ," and it is most distinctly stated that the former "have arms fitted only for walking" ‡.

These statements suffice to show that the structural peculiarities of the Ophiuridæ are such as altogether to incapacitate them for raising themselves for any distance, or lengthened period, from the bottom. Assuming, however, the possibility of their having been carried from shallow water by a current, in order to account for their adherence to such a limited portion of the sounding-line as 50 fathoms out of 1310, it is also necessary to assume that they swept past in a closely compacted column, precisely at the period when these fifty fathoms passed downwards or upwards—a contingency far from probable even if the line had been stationary, but rendered in the last degree improbable when it is borne in mind that it was moving through the water at a mean speed of at least sixty yards per minute.

Again, it is hardly possible to believe that creatures constituted to inhabit coast-lines, and dependent on the bed of the sea for their food, could have retained vitality during the time occupied in drifting the 250 miles between the

* 'Palæontology,' by Richard Owen. London, 1860: p. 29.

† 'Animal Kingdom,' by Rymer Jones, F.Z.S. London, 1841: p. 140.

‡ See 'Reports on the Progress of Zoology and Botany,' by Professor C. Th. v. Siebold. Published for the Ray Society. London, 1841-42; p. 331.

spot at which they were captured and the nearest land. The only superficial current known to exist in this region *, instead of flowing from Iceland or any of the northern coasts, flows towards them, and could not have transported these Star-fishes from any position nearer than the eastern edge of the Newfoundland banks. Of the presence of a deep-seated current there is no certain proof. I have alluded in my Diary † to the indications of a drift between the Faröe Islands and Iceland as being requisite to account for the slow transport of the volcanic particles distributed in defined belts along that region, and have stated my reasons for regarding it as a deep branch of the descending Spitzbergen current which flows under the ascending branch of the Gulf Stream in its transit to the equator. It is well known that a cold drift moves from the North and South Polar regions towards the equator in order to equalize the temperature and keep up the balance of the saline ingredients of the ocean. But in latitudes beyond the influence of melting ice this drift must necessarily flow at such depth as to involve the presence of the very conditions hitherto regarded as fatal to animal existence, and at a speed which would be insufficient to support, and far less to transport, creatures of such size and weight as those referred to. Lastly, whether the Star-fishes are supposed to have drifted to the position in which they were captured by a superficial or a deep-seated current, or to have propelled themselves from some distant coast-line, it appears to me that their vitality and healthy condition under such circumstances can only be regarded as increasing, instead of diminishing, the difficulties in the way of an explanation of the phenomena.

But, fortunately, the evidence on which I maintain that these *Ophiocomæ* were captured on the sea-bed itself, in the midst of their normal haunts, is not altogether of a presumptive kind; nor is the discovery of animal life at extreme depths restricted to two examples amongst the Ophiuridæ and Foraminifera.

Immediately on the completion of the sounding under notice, I carefully examined the digestive cavity of one of the *Ophiocomæ*. The contents consisted of a number of fresh-looking *Globigerinæ* more or less broken up, minute

* I am indebted to Sir Leopold McClintock for the following observations, which clearly attest the transit of the Gulf Stream in the locality at which the Star-fish sounding was taken:—Temperature of air 44° F.; temperature of the surface of the sea 48° F.; temperature of sea at 100 fathoms 48½° F.

† See Chapter I., p. 5 *et seq.*

yellow amorphous particles, a few bright-yellow oil-globules, and several ova. In two specimens examined at a subsequent date, I found the *Globigerinæ*, amorphous particles, and oil-globules as before, but no ova; whilst in the deposit itself were detected two small Echinoderm-spines which, on comparison, proved to be identical with those on the arms of the *Ophiocomæ*.

In three soundings (including that in which the Star-fishes were obtained) taken in the under-mentioned positions and depths—namely, lat. 59° 27′ N., long. 26° 41′ W., depth 1260 fathoms; lat. 58° 23′ N., long. 48° 50′ W., depth 1913 fathoms; and lat. 56° 43′ N., long. 11° 55′ W., depth 1268 fathoms—minute cylindrical tubes occurred, varying from $\frac{1}{8}$th to $\frac{1}{2}$ an inch in length, and from $\frac{1}{50}$th to $\frac{1}{20}$th of an inch in diameter. These were built up almost exclusively of very small Globigerina-shells and still more minute calcareous débris cemented together. Two or three such tubes were found by me in each of these soundings, but I failed to extract the animals from them in a sufficiently perfect condition to admit of identification. I am nevertheless able to state positively that the tubes contained some species of Annelid, and think it highly probable that certain borings to be seen on Foraminiferous shells in the same deposits may have been effected by it. But, whether this be the case or not, it is quite clear that an Annelid lives at the depths indicated, and *there* builds up its tenement. The shells forming the outer layer of the tubes were colourless and freed of all sarcodic matter; but the internal surface of the tubular cylinder was lined with a delicate yet distinct layer of reddish chitine.

It has been stated that these tubes are *almost* exclusively built up of Globigerina-shells. The proportion is probably about 98 per cent., the remaining 2 per cent. being made up of Sponge-spicules, Diatom-valves, and minute particles of other mineral matter.

In a sounding taken in somewhat shallower water, namely, in 871 fathoms, in lat. 61° 35′ N., long. 24° 9′ W. (about halfway between Cape Rekianess and the position of the Star-fish sounding), I detected two tubes, probably formed by the same or a closely allied species of Annelid, but differing from the last in the total absence of Globigerina-shells, and their replacement by nearly equal proportions of minute calcareous débris and Sponge-spicules. The size of the tubes in this sounding would appear to be modified by the more compact "stowage" of which their material is capable; and hence the diameter is

reduced in the two specimens to $\frac{1}{85}$th and $\frac{1}{80}$th of an inch respectively,—about 2 per cent., again, consisting of what may be regarded as accidental particles, namely, fragments of Foraminiferous shells and Diatom-valves.

The importance of these facts can scarcely be overrated; for, although the presence of Annelid-tubes neither proves the vitality of their occupants nor of the Foraminifera and Sponges which supplied the material to construct them, yet, since we know that all tubicolous Annelids are essentially ground-inhabiting creatures, it is manifest that the tubes must have been built upon the sea-bed, and hence that the living Annelids must have been there present to build them. And further, if we admit the connexion between the bored Foraminiferous shells met with in the same deposits and these Annelids, we must also admit the probability that the latter found within the bored shells suitable living nutriment to recompense them for their trouble.

But the material of the tubes supplies its share of valuable evidence likewise; for we find that whereas in the 1260- and 1268-fathom deposits, which consist chiefly of Foraminiferous shells, the tubes are formed almost exclusively of this material, in the 871-fathom deposit, which consists of a nearly equal admixture of calcareous and siliceous matter, the tubes partake of the same proportions, clearly showing that, both in the kind and quantity of material employed, the Annelid is dependent on the character of the deposit on which it lives.

In a sounding taken in lat. 63° 31′ N., long. 13° 45′ W., in 682 fathoms, a portion of a Serpula-tube, $\frac{5}{12}$ths of an inch in length, and about $\frac{3}{16}$ths of an inch in diameter, belonging to a known species, came up in such a condition as to leave no room for doubt that it had been broken off the rock or stone to which it was adherent by the sounding-machine, and that the animal was living; whilst a smaller *Serpula* and a cluster of apparently living Polyzoa were adherent to its external surface. A minute living *Spirorbis* also occurred in this sounding. Lastly, from a depth of 445 fathoms, within a short distance of the south coast of Iceland, a couple of living Amphipod Crustaceans were obtained, and a filamentous Annelid about three-quarters of an inch in length.

Bearing in mind, then, 1st, that the *Globigerinæ* have never been detected free-floating in any number in deep, or forming deposits in shallow water; that a considerable proportion of those met with in the deep-sea deposits exhibit every appearance of vitality; that their maximum development is associated with

the presence of the Gulf Stream, but only through the operation of collateral conditions prevailing at great depths below the current itself; and that fresh-looking specimens were present in the digestive cavities of *Ophiocomæ* brought up from a depth of 1260 fathoms;

2ndly. That the *Ophiocomæ* arrived at the surface in a living and vigorous condition, adherent to that portion only of the sounding-line which had rested on the bottom; that the number captured affords presumptive proof of the gregarious habit of the order having remained unaffected by change of conditions; that the detection of ova and *Globigerinæ* within their cavities indicated a perfectly normal state of their reproductive and nutritive functions; that no superficial or deep current capable of drifting them in a northerly or north-easterly direction from any coast-line nearer than Newfoundland exists in this part of the ocean, and, if it did, that it would not account for the most important phenomena;

3rdly. That in certain deposits Annelid-tubes were found, the nature of which proves them to have been constructed on the sea-bed, of material there accumulated;

4thly. That a living *Serpula*, *Spirorbis*, and group of Polyzoa were brought up, in a distant locality, from a depth of 680 fathoms;

5thly and lastly. Taking into consideration the arguments adduced to prove that the conditions which prevail on the deep-sea bed are not incompatible with the maintenance of animal life, and the extreme improbability that the creatures heretofore discovered at great depths are merely exceptional or accidental examples; it will, I think, be conceded that the presence of a living fauna in the deeper abysses of the ocean has been fully established.

Assuming, then, that the creatures referred to were captured in the midst of their normal haunts, the inquiry naturally suggests itself, Whence did they originate? and are we to regard the localities in which they were found as their genetic centres, or only as isolated colonies tenanted by species whose genetic centres are to be looked for elsewhere? These questions can only be answered by a further appeal to concomitant facts.

"Every living race of plants and animals," writes Professor Phillips, "exists in a province of space over which by natural conditions it has been diffused, within which by natural conditions it has been restrained, and beyond which it only passes by a change in these conditions. Thus one place of origin is indi-

cated for each species of plant and animal—one locality where it first appeared. whether it still remain there confined to a limited region, or have wandered far away without losing its prominent characters through length of time, change of conditions, mixture with other races, or any of the innumerable incidents of the 'struggle for existence'" *.

Bearing in mind the law thus comprehensively set forth, and connecting it with the extraordinary fact that the *Ophiocomæ*, the *Serpula*, and the *Spirorbis* of the deep soundings one and all belong to well-known littoral species†, we are irresistibly led to the inference that their acclimatization must have kept pace. during a vast sequence of generations, with the changes going on in the portion of the sea-bed inhabited by them, and, hence, that, under sufficiently favourable circumstances, species may accommodate themselves to conditions differing so widely from those under which they were originally created, that their subjection to them under circumstances less favourable inevitably results in their extinction.

I have endeavoured to establish that an extensive area of sea-bed to the southward of Iceland has undergone subsidence, partly on the evidence afforded by the depths, and partly by that supplied from old charts and tradition. The subjoined striking passage from Forbes's admirable memoir "On the Existing Fauna and Flora of the British Isles" will serve to show that, on geological grounds alone, he arrived at a similar opinion:—"Great as the changes appear to be affecting the distribution of land and water during recent geological periods, as compared with the present, assumed by me in this essay, I cannot but express my conviction that future research will not only confirm these, but prove that still greater took place during the epochs under inquiry. The phenomena of the glacial formations, the peculiarities in the distribution of the animals of that epoch, and the relations of the existing fauna and flora of Greenland, Iceland, and Northern Europe are such as strongly to impress on my mind that the close of the Glacial epoch was marked by the gradual submergence of some great northern land, along the coasts of which the littoral Mollusks, aided by favouring currents, migrated; whilst a common flora became diffused over its hills and plains. Although I have made icebergs and ice-floes the chief agents in the transportation of an Arctic flora southwards, I cannot but think that so complete a transportation

* 'Life on the Earth,' by Professor Phillips. London, 1860: p. 24.

† The species are *Ophiocoma granulata*, *Serpula vitrea*, and *Spirorbis nautiloides*.

of an Arctic flora as we find on the Scottish mountains was aided, perhaps mainly, by land to the north now submerged. It is difficult otherwise, too, to account for the cessation of the Arctic littoral Mollusks in the Scottish glacial beds, and their replacement by other forms on the English and Irish beds of the same epoch. When dredging on the great fishing-banks bounding the Zetland Isles and forming long ridges now 50 and more fathoms below the sea, stretching from some unexplored point in the north, like long arms, down to the Scottish shores, and covered with angular fragments of the rocks of which they are formed, I was strongly struck with their resemblance to the rugged and broken surfaces of the neighbouring islands, and could not divest myself of the notion that these banks were submerged mountain-chains. Before, however, this can be fairly assumed, we must have a re-examination of the vegetable and animal productions of Iceland, that great centre of volcanic power, the presence of which where it is, is possibly connected intimately with the phenomena we have been endeavouring to interpret" *.

The outline thus shadowed forth of that ancient barrier which is supposed to have stretched across from East Greenland (probably, however, at some point far to the northward) towards the shores of Northern Europe derives a singular degree of confirmation from the soundings. For, on reference to the map, it will be seen that a vast area of sea-bed to the southward of Iceland, extending to the 30th degree of west longitude on the one hand, and to the Faröe Islands and Hebrides on the other, gradually diminishes in depth as it advances northwards, in all probability constituting the boundary of an archipelago rather than a continuous continent, across which the various species of animals and plants made their way southwards. When that archipelago existed, the Hebrides and Faröe Islands were probably united, whilst Rockall formed a large but distinct island, and another still larger island rose up out of the sea between the 57th and 60th degrees of latitude, and about the 30th degree of west longitude. On the northern flank of this island the Star-fish sounding was taken. Lastly, the Faröes and Iceland were then separated only by a narrow channel, situated about the 15th

* 'Memoirs of the Geological Survey of Great Britain,' vol. i. p. 398.

I cannot refrain from here paying my humble tribute of admiration and respect to a lamented friend and college-mate. The first time I ever saw a dredge put down was in the Firth of Forth, in company with Edward Forbes, nine and twenty years ago.

degree of longitude, whilst the Westmann Islands and the Blinde Skier respectively formed portions of the southern and south-western coast-line of Iceland.

Viewed by itself, the subsidence of this large tract, although of interest as yielding a glimpse of the facies of the ancient Atlantic, and even suggestive of the acclimatization of the creatures now distributed over its bed, could hardly have been regarded in a higher light than as offering a plausible explanation of a most unlooked-for phenomenon. But it assumes a far more important bearing when coupled with the fact that these creatures belong to existing shallow-water species, and that they exhibit no appreciable trace of variation, notwithstanding the change of conditions to which they have been subject for a vast series of generations. In short, no proof of subsidence could be more complete, no proof of the truth of the doctrine of single specific centres more convincing, than the detection under such circumstances of a colony of acclimatized Star-fishes, belonging to a species typical of the Boreal province, well known to range from the confines of the arctic circle to our own shores, and already shown to have accommodated themselves to a depth of 200 fathoms without variation; whilst the fact of subsidence being general throughout the whole area is rendered probable by the discovery of sessile Annelids, also belonging to known shallow-water species, at a depth of 680 fathoms, halfway between Iceland and the Faröe Islands.

The occurrence of a shallow-water *Serpula* at such a depth is important, moreover, from the evidence it yields of the subsidence having been extremely gradual, and not merely the result of local and temporary submarine volcanic action; for, whilst creatures having powers of locomotion might have evaded the consequences of sudden subsidence by migration to shallow water, the sessile Annelids must inevitably have been destroyed. If these facts are correct, the detection of shallow-water species on isolated submerged areas of sea-bed may yet enable us to determine whether such areas have been nearer the surface at some anterior period, and may thus afford us a glance, otherwise unattainable, at the lost landmarks of a bygone geological epoch.

It will perhaps be asked how it is that the *Ophiocomæ*, if descendants of a littoral species, exhibit no definite divergence of character from individuals of the same species which have never been removed from normal conditions. To this it may be answered that certain orders of animals are known to be much

more prone to variation dependent on changes in the conditions by which they are surrounded than others, whether we regard the variation observable in the same individual or the same species at different periods of its history*. And, further, if the views offered by me are correct, it is evident that such changes of conditions must operate more frequently and powerfully at the surface than at great depths. Now, since *Ophiocoma granulata* is found on the British and Scandinavian coasts at depths varying from 10 to 50 fathoms, whilst in Greenland, as already stated, it is met with at 200 fathoms, it is reasonable to suppose that, if prone to variation, it would exhibit clear traces of it at the greater of these depths. Such is not the case, however; and hence the persistence of type at the still more profound depth of 1260 fathoms becomes intelligible, although nevertheless surprising.

It has already been stated that *Orphiocoma granulata* ranges at the present day from the confines of the arctic circle to our own shores. I failed to detect it in the immediate neighbourhood of Rekiavik, but this was probably in consequence of the peculiar scoriaceous nature of the bottom along the south-western portion of the island. In the absence of data for determining whence the species became diffused across such a wide longitudinal range, it would be useless to speculate whether the isolated deep-sea area on which it has now been found formed its genetic centre; whether the transport or migration of individuals towards that area took place prior to its isolation and complete submergence; or whether it was colonized after isolation. From what has been stated regarding the inability of the Ophiuridæ in their mature state to rise to any distance or for any lengthened period from the bottom, it is apparent that transport of individuals could only be effected by a powerful current. During the larval condition, however, of certain species of Ophiuridæ, they sometimes float at the surface of the sea, and, hence, under favourable circumstances, might be drifted towards isolated areas fitted to receive them. In the Foraminiferous deposit of the Agulhas bank, I dredged up larval Ophiuridæ, from a depth of 100 fathoms, measuring not more than a quarter of an inch across the arms, whilst specimens obtained from the immediate surface over the same deposit were of still more minute dimensions. These had, in all probability, drifted from the adjacent

* According to Edward Forbes, no important variation has taken place in the Ophiuridæ since the extinction of the species found fossil.

coast-line, and were destined to subside to the bottom as soon as their calcareous structure became sufficiently consolidated to counterbalance the buoyancy of the soft parts*. In the case of the *Ophiocomæ* of the sounding, the presence of ova distinctly proves that the generative function was being carried on even at that great depth; and consequently the undetermined state of the question regarding the genetic centre of the species is of very secondary importance; for, whether the submerged area was colonized by emigrants from adjoining coasts, prior to its isolation, or by larval *Ophiocomæ* which had subsided upon it after it had become partially or completely submerged, the phenomenon of subsequent acclimatization (which is the one more particularly under consideration) remains entirely unaffected.

Another very singular fact in connexion with the Star-fish sounding demands notice, namely, its proximity to the circle of uniform temperature†. It will be recollected that the sounding was taken in lat. 59° 27′ N., whereas the mean latitude of the homothermal circle, according to Sir James C. Ross's observations in the southern hemisphere, is 56° 25′ ‡. The position corresponding most closely, in the Southern Sea, with that of the Star-fish sounding is in lat. 58° 36′ S., long. 104° 40′ W.—a position at which it is stated to be "about a degree higher than in other parts of the ocean, and also rather further to the southward." In this situation the temperature of the air is stated to have been 32° F., of the surface 41°, and at 100 fathoms 40°·8 §; whereas, in the locality of the sounding,

* In 1850, Mr. T. H. Stewart detected a larval *Ophiocoma* in abundance on a parasitic sponge brought up from a depth of 53 fathoms in the British Channel. The same larval form was also met with in pools left by the receding tide,—the fact of its being found both in shallow and deep water being regarded as proof that the mature animal spawns in both situations. (Annals and Magazine of Natural History, 2nd ser. vol. xviii. p. 387.)

† It is worthy of note that on the Agulhas bank, to the southward of the Cape of Good Hope, where fish are abundant, the bottom consists of calcareous deposit, and that to the northward of Rockall (where an extensive fishery has recently been re-discovered) the bottom is essentially of a similar character, Echinoderm-débris being so plentiful in both localities as to render it probable that the Echinoderms form the food of the fish. Should shallow water still exist in the vicinity of the reputed "Sunk land of Buss," it is possible that a more inexhaustible fish-bank than any yet known may be there met with. It is also remarkable that Loch Fyne, the Dogger Bank and Silver Pits, the Rockall Shoal, and the Labrador and Newfoundland fisheries are all either on, or near, the circle of uniform temperature—a coincidence in position which can hardly be regarded as accidental.

‡ See diagram at p. 99.

§ The mean latitude of the homothermal zone as computed by Sir James C. Ross, in the southern hemisphere, is here given. (See 'Voyage to the Southern Seas,' vol. ii. pp. 227 and 375.)

the temperature of the air was 44°, of the surface 48°, and at 100 fathoms 48½°,—clearly indicating the effect of the Gulf Stream both on the air and water.

It would be futile to speculate on the probable influence which such a region of uniform temperature from surface to bottom may have had upon the bathymetrical distribution of animals, since the nature of the conditions under which acclimatization commences presupposes a period so remote that the sea-bed must have been elevated almost to the surface: but it is not unreasonable to suppose that, as subsidence took place, the increasing uniformity in the temperature and density of the water may have facilitated their acclimatization, and eventually favoured their distribution over the bed of the homothermal sea.

It only remains for me to mention that I have met with no example of any of the Algæ proper below 200 fathoms, and that the only recognizable vegetable structures which occur amongst the deep-sea deposits belong to the lowest order with which we are acquainted, namely, the Diatomaceæ. As already mentioned, however, the appearance presented by the frustules of these, when obtained at depths beyond 500 fathoms, indicates a molecular constitution of the protoplasmic matter differing so materially from that observable in similar organisms taken in a living condition in shallow water as to render it certain that all vegetable life ceases at a limit far short of that to which animal life has now been shown to extend.

Basing my arguments, then, on two facts which I venture to hope are unequivocally proved in the preceding pages, namely, that highly organized creatures have been captured in a living condition at depths vastly exceeding those to which animal life had previously been supposed to extend, and that their presence, where captured, cannot be regarded as an accidental or exceptional phenomenon, it has been my endeavour to establish the following important propositions:—

I. The conditions prevailing at great depths, although differing materially from those which prevail near the surface of the ocean, are not incompatible with the maintenance of animal life.

II. Assuming the doctrine of single specific centres to be correct, the occurrence of the same species in shallow water and at great depths proves that it must have undergone the transition from one set of conditions to the other with impunity.

III. There is nothing in the nature of the conditions prevailing at great depths,

to render it impossible that creatures originally, or through acclimatization, adapted to live under them should become capable of living in shallow water, provided the transition be sufficiently gradual; and hence it is possible that species now inhabiting shallow water may, at some anterior period, have been inhabitants of great depths.

IV. On the one hand, the conditions prevailing near the surface of the ocean render it possible for organisms to subside after death to the greatest depths, provided every portion of their structure is freely pervious to fluid: on the other hand, the conditions prevailing at great depths render it impossible for organisms still constituted to live under them to rise to the surface, or for the remains of these organisms after death to make their appearance in shallow water.

V. The discovery of even a single species living normally at great depths warrants the inference that the deep sea has its own special fauna, and that it has always had it in ages past; and hence that many fossiliferous strata, heretofore regarded as having been deposited in comparatively shallow water, have been deposited at great depths.

PART III.

CHAPTER I.

GENERAL OBSERVATIONS ON THE DEEP-SEA RHIZOPODAL FAUNA.

BEFORE proceeding to describe the minute structures which constitute the principal organic element in the North Atlantic soundings and are distributed more or less abundantly throughout all the deep-sea deposits of the globe, it is necessary to adduce my reasons for having embodied in the present work a general classification of the lowest orders of the animal kingdom which might, with greater propriety perhaps, have formed the subject of a separate memoir.

In preparing for publication the materials at my command I had the choice of two alternatives—that is, either to arrange them according to some artificial system solely with a view to the future identification of particular forms, or, turning aside from the easy but profitless task of species-manufacture, to apply myself to the more legitimate purpose of increasing our knowledge regarding the morphological and physiological characters of the class of creatures to which, with a few rare exceptions, the various organisms belong.

The elaborate researches of Carpenter, Messrs. Parker and Jones, Williamson, Schultze, MM. Claparède and Lachmann, Carter, and others, had already placed in an entirely new light the nature and relations of the *Gromida*, *Foraminifera*, *Actinophryna*, and *Amœbina*; whilst those of Johannes Müller * had put us in possession of much valuable information respecting the *Polycystina* and some allied but still more imperfectly known families of Rhizopods. The *Foraminifera*, with the single exception of the genus *Globigerina*, were neither largely represented in

* 'Über die Thalassicollen Polycystinen und Acanthometren des Mittelmeeres,' von Johannes Müller. Berlin, 1848.

the soundings, nor did they exhibit any very novel or striking characteristics. The study of this family, moreover, was undergoing such a thorough revision by the distinguished physiologist whose name stands at the head of the above list, that any attempt on my part to have forestalled his labours would simply have been presumptuous*. The *Polycystina*, on the other hand, were both more abundantly represented than the *Foraminifera*, and exhibited such an endless variety of form as fully to confirm the opinion at which I had long previously arrived—partly on an examination of living specimens procured in the surface-waters of the tropical seas, and partly from the study of the fossil Polycystine earths,—namely, that in no class of organisms is the tendency to variation more unlimited, or the law of development less understood. To Professor Müller's views regarding the proper basis for a classification of the *Polycystina*, *Acanthometrina*, and *Thalassicollidæ*, it was impossible for me to subscribe, inasmuch as I differed from him not only in the value to be placed on mere differences in form and the mode of repetition of the siliceous portions of these structures, but in the interpretation of those more important characters upon which the ordinal separation of the whole of the Rhizopodal families has, in great measure, been made to depend.

Under these circumstances, and in the firm conviction that the mere description and delineation of a number of objects, with no higher aim than that of augmenting the already perplexing lists of doubtful species, would serve no useful purpose, I resolved to attempt a revision of the classification of the Rhizopods, and to import into it as much of the information obtained, both from the soundings and from other sources, as might be necessary for the due completion of my object.

In a valuable paper by Professor Carpenter, 'On the Systematic Arrangement of the Rhizopoda," which appeared in the Natural History Review for October 1861†,

* In the 'Introduction to the Study of the Foraminifera' (page 56), Dr. Carpenter declares that "The impracticability of applying the ordinary method of definition to the *genera* of *Foraminifera*, becomes an absolute impossibility with regard to species."

† It is necessary to state that the following pages were written subsequently to the appearance of Dr. Carpenter's paper in the 'Natural History Review,' and that his admirable 'Introduction to the Study of the Foraminifera' appeared whilst they were passing through the press. As Professor Carpenter's detailed work in nowise contravenes the views expressed in the preliminary paper referred to, I have only felt called upon to modify a few unimportant passages.

the characters of the three orders into which he proposes to distribute the various families are concisely stated as follows:—

"I. RETICULARIA. The body composed of homogeneous granular protoplasm, without any distinction into ectosarc and endosarc; neither nucleus nor contractile vesicle; pseudopodia composed of the same substance as the body, extending and multiplying themselves by minute ramification, and inosculating completely wherever they come into contact; a continual circulation of granular particles throughout the viscid substance of the body and its extensions. This Order consists of the *Foraminifera* and the *Gromida*.

"II. RADIOLARIA. Incipient differentiation of the protoplasmic substance into ectosarc and endosarc, the former semifluid and granular, the latter more tenacious and pellucid; a nucleus and contractile vesicle; pseudopodia rod-like, usually tapering from base to point, composed of the same substance as the ectosarc, exhibiting little disposition either to ramify or to coalesce, having a more or less regular radiating arrangement, and not showing any constant circulation of granules in their substance, although a movement of particles adherent to their exterior is often to be distinguished. The type of this Order is *Actinophrys*, constituting, with its immediate allies, the family *Actinophryna*; but the Order also includes the *Acanthometrina*, *Polycystina*, and *Thalassicollina*, by the last of which this group is connected with the Sponges.

"III. LOBOSA. More complete differentiation of the protoplasmic substance into endosarc and ectosarc, the former being a slightly viscous granular liquid, and the latter approaching the tenacity of a membrane; a nucleus and contractile vesicle; pseudopodia few and large, being in reality lobose extensions of the body which neither ramify nor coalesce, having well-defined margins, and not exhibiting any movement of granules on their surface, the circulation in their interior being entirely dependent on the changes of form which the body undergoes as a whole. This Order is composed of but a single family, the *Amœbina*, and it is the one which presents the nearest approximation to the Classes *Infusoria* and *Gregarinida*."

It will be seen that whilst these definitions are almost wholly based on the degree of "differentiation" exhibited by the general mass of the sarcodic substance, the names of the Orders point exclusively to the characters of the pseudopodia. For, whether we regard the degree of consolidation of the

superficial protoplasmic layer of the organism—the capability or otherwise of the pseudopodial processes to maintain a separate individuality so long as they remain projected beyond the main mass of the body—the apparent character of the minute granular circulation, either as occurring within the general cavity of the organism or extending *into* the pseudopodia—or the presence or absence of a nucleus and contractile vesicle,—we perceive that the whole of these characters have a mutual dependence one on the other, and are exponents of the gradual advance from that simplest phase of animal being in which the structure is distinguishable from an inanimate jelly only by the cyclosis of granules and the projection of pseudopodia, to the highest phase of Rhizopodal development, in which the characters merge into those of the *Spongidæ* on the one hand and the ciliated *Infusoria* on the other.

Being fully convinced that the principle of classification so admirably propounded by Dr. Carpenter is the only one on which a natural distribution of the Rhizopodal Orders can be established, it is with great diffidence that I now venture to offer such a modification of his arrangement as I conceive to be demanded, not by a conflict of opinion regarding the value of certain characters, but the presence or absence of those characters in some of the families said to exhibit them. At the same time it is a satisfaction to feel that my views diverge from his, for the most part, only in those cases in which his judgment has been based on the descriptions of other observers, and not on personal examination of the living structures.

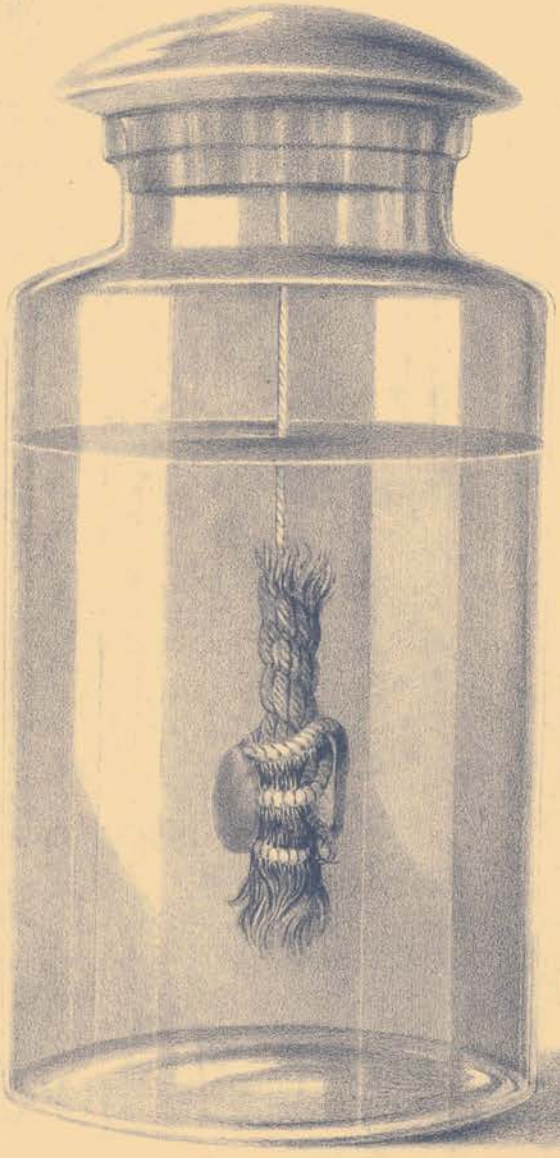
The principal source of confusion has arisen, I conceive, from Professor Müller's statements with reference to the nature and characters of the pseudopodial processes in the *Polycystina* and *Acanthometrina*—statements which clearly tend to indicate a similarity, if not an identity, in the pseudopodia of these two families, although I cannot admit that they warrant the conclusion that any dissimilarity existed, in Professor Müller's opinion, between those of the *Polycystina* and *Foraminifera*. In drawing attention to the additions to our previous knowledge of the Rhizopods, supplied in Professor Müller's treatise 'Über die Thalassicollen, Polycystinen und Acanthometren des Mittelmeeres,' Dr. Carpenter speaks of the author as having failed to appreciate the essential relationship between the *Acanthometrina* and *Actinophryna*, "an *Acanthometra* being nothing else than an *Actinophrys* furnished with a siliceous skeleton." As described by

Müller, it would certainly seem to be nothing else; but I hope to be able to prove as I proceed, not only that the *Acanthometrina* do not possess radiate pseudopodia analogous to those of *Actinophrys*, but that *Acanthometra* is as far removed beyond *Actinophrys*, in the degree of development attained by the ectosarc*, as *Actinophrys* is beyond *Pamphagus* or *Lieberkuhnia*, whilst the *Polycystina*, which are ranged with the *Acanthometrina* in Professor Müller's system, do not exhibit any advance in the degree of differentiation of the protoplasmic substance beyond that observable amongst the *Foraminifera*. Hence it would appear that the separation of *Actinophrys* and *Amœba*, in Dr. Carpenter's system, is due rather to an assumed but unreal affinity between *Actinophrys*, *Acanthometra*, and the *Polycystina* than to any valid distinction between the characters of the two first-named genera; for it must be admitted that the disinclination of the pseudopodia to coalesce, and the presence of a nucleus and contractile vesicle (the last of which organs is never to be met with in the *Polycystina*, the *Acanthometrina*, or the *Thalassicollidæ*) are characters of far higher significance than the apparent absence of granular circulation in *Actinophrys*, which is seen in *Amœba*, and the mere difference in size, shape, and persistence of each pseudopodial extension. I say, *apparent* absence of granular circulation, because it is difficult to conceive that in two organisms varying but little, if at all, in the average consolidation of their ectosarc, and both possessing a nucleus and contractile vesicle (the last of which organs Dr. Carpenter† considers as "superseding the necessity of the general protoplasmic circulation"), such a difference should exist—or, if it exists, that it should be deemed of distinctive value.

Had the close analogy between *Actinophrys* and *Acanthometra* really subsisted, it is hardly possible that Professor Müller could have failed to detect it notwithstanding the fact that his reliance on the characters furnished by the hard parts would naturally have led him to regard these two families as distinct. But he leaves no room for doubt as to his views concerning the pseudopodia of the Rhizopods under notice; for he distinctly states that, having had an opportunity

* The very appropriate terms *ectosarc* and *endosarc* were originally applied by Dr. T. Strethill Wright to the external condensed layer and the internal viscid mass of the sarcode of the Rhizopods.

† "On the Systematic Arrangement of the Rhizopoda," by William Carpenter, M.D., F.R.S., 'Natural History Review,' No. 4, Oct. 1861, p. 462.

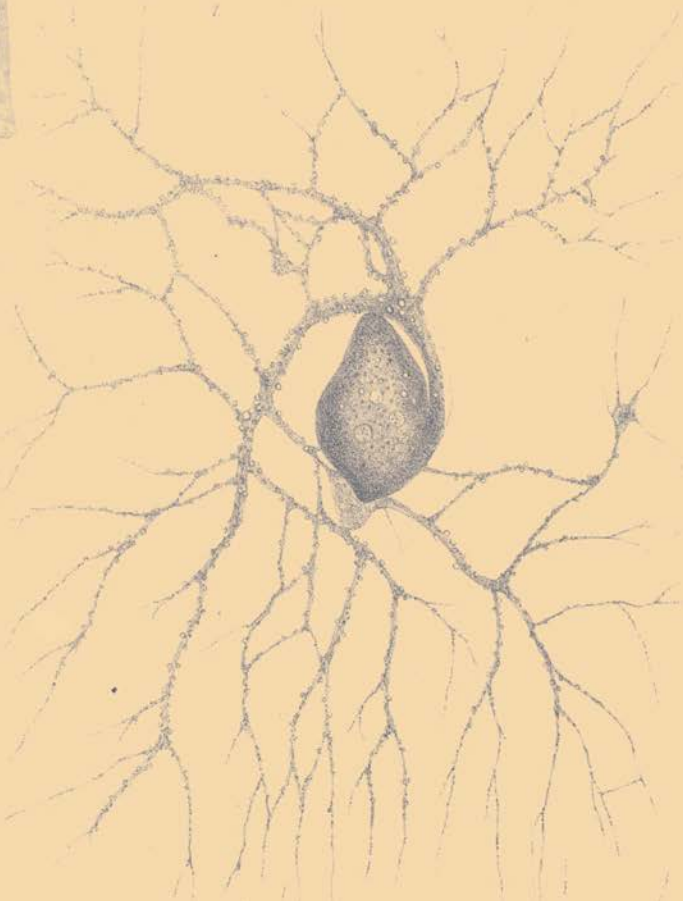


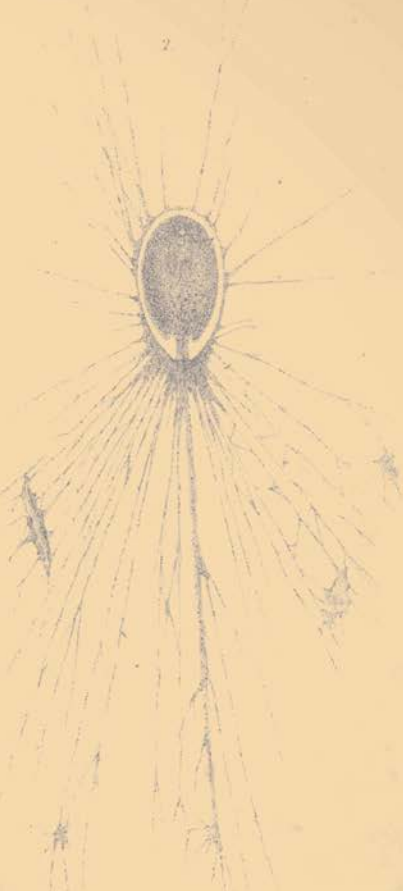
G. C. Wallich del et lith.

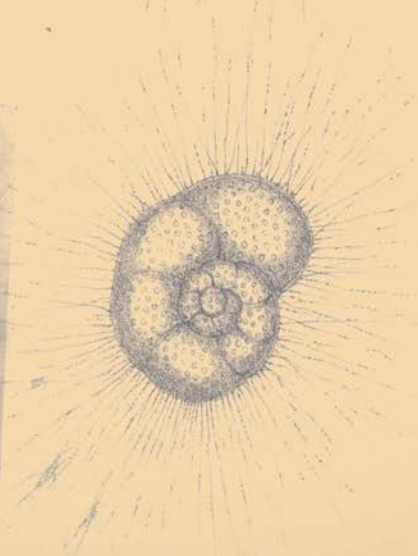
M & N. Hanhart, Imp.

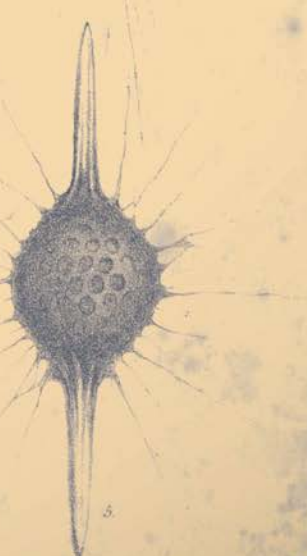
OPHIOCOMA, ADHERING TO THE SOUNDING LINE, IN THE POSITION IN WHICH IT REACHED THE SURFACE FROM A DEPTH OF 1260 FATHOMS.

John Van Voorst, Paternoster Row, 1862









LIEBERKUHNIA. GROMIA. DISCORBINA. MILIOLA. HALIOMMA.

John Van Voorst, Paternoster Row, 1862.

PLAGIOCANTHA. LITHOCIRCUS. ACANTHOMETRA.
THALASSICOLLA. DICTYOCHA. ACTINISCUS.

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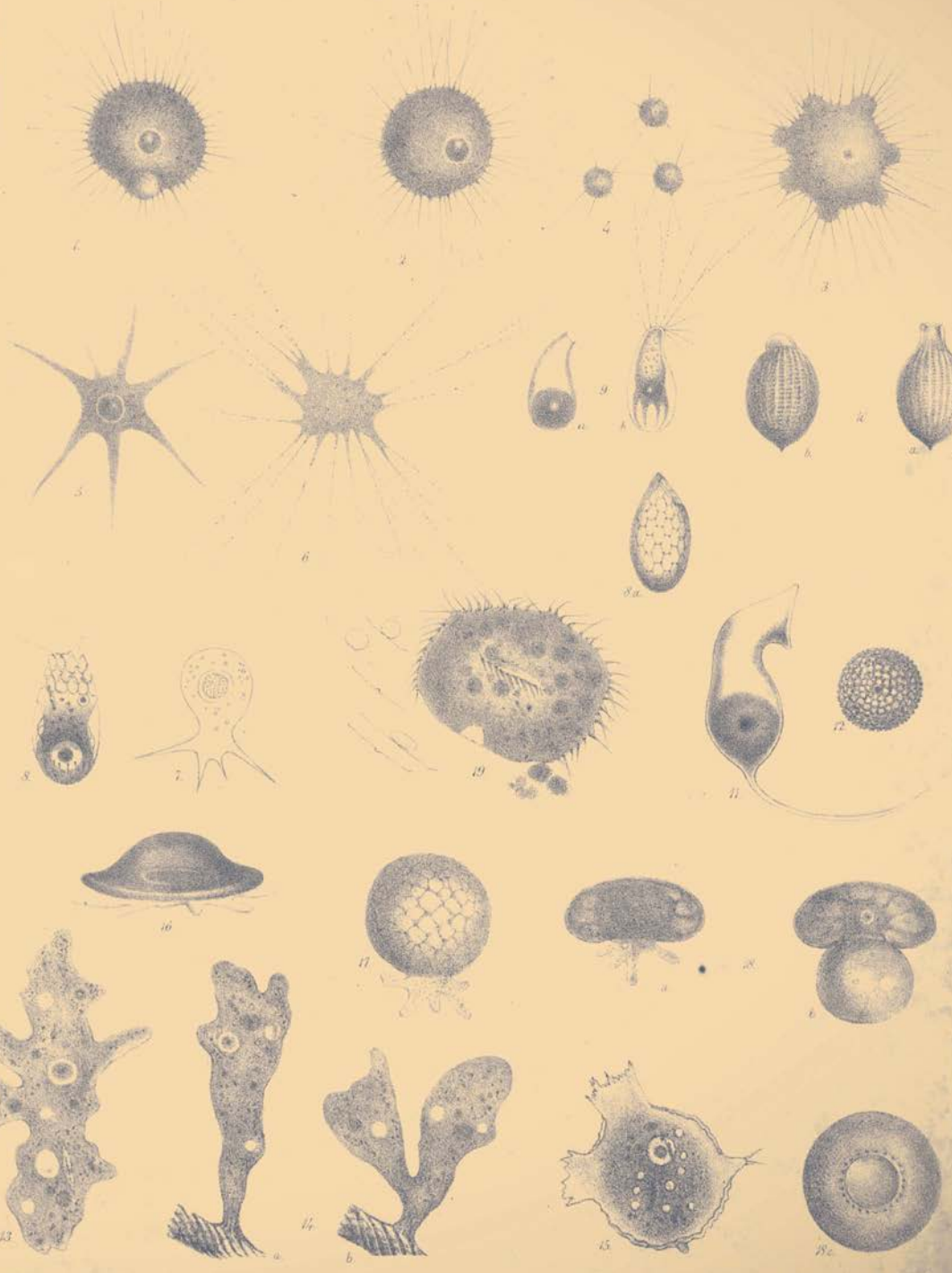
RHIZOPODA.

ORDER 3. PROTEINA



ACTINOPHRYS. LAGYNIS. EUGLYPHA. CADIUM. PROTOCYSTIS.
ACANTHOSPHŒRA. AMŒBA. DIFFLUGIA. ARCELLA.
(HERONA)

G.C. Wallich, lith. Vincent Brooks, Imp.
John Van Voorst, Paternoster Row, 1862

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BILOCULINA. QUINQUELOCULINA. SPIROLOCULINA.
CORNUSPIRA. LAGENA.

John Van Voorst, Paternoster Row, 1862.

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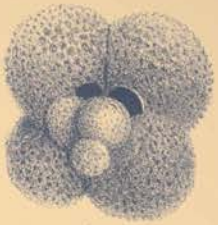
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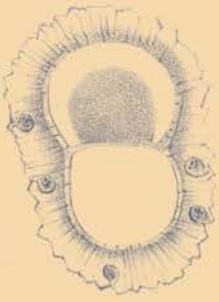
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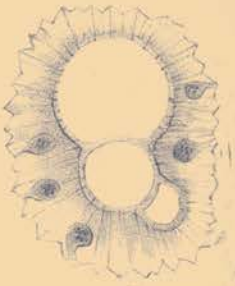
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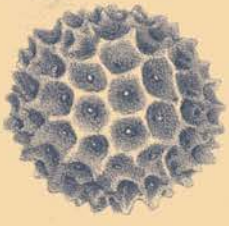
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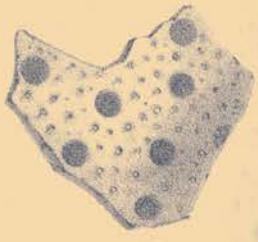
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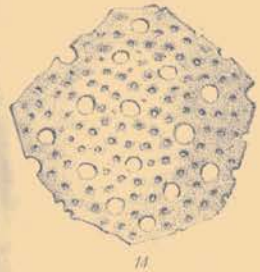
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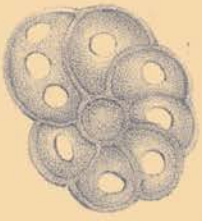
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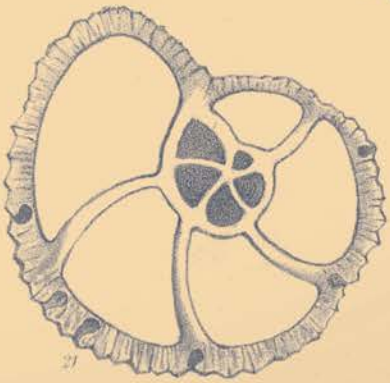
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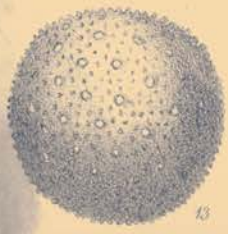
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GLOBIGERINA. ORBULINA. DISCORBINA. LITUOLA. ROTALIA.

John Van Voorst, Paternoster Row. 1862.

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